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REFLECTANCE MEASUREMENTS FOR THE DETECTION AND MAPPING OF SOIL LIMITATIONS

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Remote Sensing Institute
South Dakota State University
Brookings, South Dakota

March 1973

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Interim Technical Report

REFLECTANCE MEASUREMENTS FOR THE DETECTION AND MAPPING OF SOIL LIMITATIONS

by

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to

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ABSTRACT

During 1971 and 1972 research was conducted on two fallow fields in the proposed Oahe Irrigation Project to investigate the relationship between the tonal variations observed on aerial photographs and the principal soil limitations of the area. A grid sampling procedure was used to collected detailed field data during the 1972 growing season. The field data was compared to imagery collected on May 14, 1971 at 3050 meters altitude.

The imagery and field data were initially evaluated by a visual analysis. Correlation and regression analysis revealed a highly significant correlation between the digitized color infrared film data and soil properties such as organic matter content, color, depth to carbonates, bulk density and reflectivity. Computer classification of the multiemulsion film data resulted in maps delineating the areas containing claypan and erosion limitations. Reflectance data from the red spectral band provided the best results.

Interpretation of the results revealed higher surface reflectivity and therefore increased film transmittance in the claypan and eroded areas. The higher reflectivity in claypan areas was primarily due to the mixing of the light-colored A2 horizon overlying the claypan during tillage and the higher reflectivity of eroded soils was primarily due to the exposure and incorporation of the light-colored, calcareous parent material. The research validated the techniques used in the past and provided a basis for the mapping of soil limitations over large areas.

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INTRODUCTION

Our present standard of living can only be maintained by wise management and judicious use of our resources. History has recorded the fall of other great civilizations that failed in this task. Wise management and planning require current information. In the case of land management the requirement is ultimately for a map or maps portraying information regarding soils, geology, climate, vegetation and cultural geography. In the past this requirement has been met by published soil surveys and maps which reflect the suitability and limitations of land for various uses.

Although informative and useful, soil surveys are expensive and slow to complete using current techniques. Considering the costs of mapping, compilation, editing and printing the average soil survey costs approximately 30 cents per acre. This cost is probably not significant on land costing $300 per acre, but could be significant on $30 land. Currently soil surveyors map approximately a section per day in cropland areas when weather permits. At this rate it takes several years to map a county and additional years to compile and publish the final product. The soil survey of South Dakota was begun in 1919 and is scheduled for completion in 1990.

The advent of remote sensing offers the soil surveyor new tools that can speed and improve the collection and compilation of soils information, but many questions remain unanswered. The big question is where does this new technique fit into the present system and how can it be used. The following report demonstrates the potential

usefulness and validity of remote sensing for the mapping of soil limitations in the proposed Oahe irrigation project in South Dakota.

The project was a part of the overall soil limitation study conducted by Dr. C. J. Frazee in conjunction with the Remote Sensing Institute and the Plant Science Department at South Dakota State University. The project utilized imagery obtained during the 1971 growing season and ground truth collected during 1971 and 1972. Previous work had shown that photographs taken during May contained obvious patterns and tonal contrasts that could be delineated by density slicing (Frazee, Heil and Westin, 1971; Frazee, Myers and Westin, 1972). A field check indicated that these patterns were associated with soil limitations. Because these limitations generally were not reflected on the published soil survey of the area due to its small scale (1:62,500), a more detailed survey was required to determine which soil properties were responsible for the tonal variation on the photograph.

Objectives

The overall objective of this research was to develop a method for detecting and mapping soil limitations with remote sensing techniques. The specific objectives were:

1. To obtain detailed information on specific soil properties characteristic of soil limitations from selected sites.
2. To determine the relationship between the soil properties measured and the tonal variations observed on photographic film.

3. To determine which band of the visible spectrum provides the best information for detecting soil limitations.
4. To develop a procedure for the analysis of field data and remotely gathered data that utilizes the state-of-the-art data analysis systems available at the Remote Sensing Institute.

LITERATURE REVIEW

The following literature review consists of two parts. The first pertains to remote sensing in general, and the second to remote sensing of soils. Although some of the material presented may at times seem fundamental, the author feels that it is necessary to present these basic concepts that provide the basis for the assumptions and hypothesis that follow.

Definition

Remote sensing can be defined simply as detecting the nature of an object from afar. A more specific or scientific definition denotes the joint effects of employing modern sensors, data processing equipment, information theory and processing methodology, communications theory and devices, space and airborne vehicles, and large-systems theory and practice for the purpose of carrying out aerial or space surveys of the earth's surface (Luney and Dill, 1970).

History

A review of the history of remote sensing reveals that until recently, military applications have over-shadowed any peacetime applications. The invention of the daquerreotype in 1839 gave man his first recording sensor and in 1858, Tournachon photographed a French village near Paris, France from a balloon (Quackenbush, 1960). The advent of the airplane in 1909 and improvements in photographic emulsions and bases provided considerable impetus to the popularity and usefulness of aerial photography. In World War I

the importance of aerial reconnaissance and photo intelligence was clearly demonstrated; and improvements in cameras, films and techniques followed. World War II provided the stimulus for striking advances in techniques of photo interpretation and more sophisticated cameras and films to match the faster high-flying aircraft. The research and development of the war resulted in the invention of radar and the first large rockets. In the following Cold War years, the need for military intelligence spurred the development of high resolution film, precision cameras and lenses with expanded focal lengths, and aircraft capable of flying outside the limits of the atmosphere. It was also during this period that color and color infrared film became popular. Today orbiting satellites carrying cameras and other detection devices keep a watchful eye on the earth below and provide information on missile firings, military buildups, and weather conditions.

With the exception of the photographic programs of the United States Department of Agriculture and the photomapping done by the United States Geological Survey, most of the technology developed by the military was not adapted to peacetime applications until the establishment of the National Aeronautics and Space Administration (NASA). Since that time we have seen the amazing accomplishments of the space program. The mapping of the moon by the Orbiter satellites and the subsequent exploration by the remote controlled Surveyor craft were particularly impressive.

With the completion of the Apollo program, NASA has directed

more of its effort to the study of earth resources. Through this program much of the technology developed by the military and for the space program is finding application in the fields of agriculture, oceanography, climatology, cartography, and geography. The launching of the Earth Resources Technology Satellite (ERTS) and the SKYLAB project hold exciting promise for the future of remote sensing. With construction of the Earth Resources Observation Satellite (EROS) Data Center to serve as a depository for satellite imagery, investigators and users of remote sensing data will have ready access to a wide variety of resource information.

Prerequisite to any discussion of the study of soil limitations by remote sensing is a general understanding of the principles and concepts of the medium, the forces or dynamics affecting the medium, and the methods of measurement.

Principles

The medium in general is energy and more specifically solar energy. According to Bethe's theory, the energy radiated from the sun is created through a complex thermonuclear reaction that converts protons (hydrogen nuclei) to alpha particles (helium nuclei). In the process mass is converted to energy. The energy emitted by the sun travels through space at the speed of light (186,000 miles/sec) and with the exception of periodic solar flares is fairly constant. This constant flow of energy powers the atmospheric heat engine that controls our weather and is the source of all energy here on earth (Miller and Thompson, 1970).

With the exception of cosmic rays which behave as particles, solar radiation is emitted as waves and travels in a straight line through space at several wavelengths. This range of wavelengths is referred to as the electromagnetic spectrum (Figure 1). Wavelengths within this spectrum are related to the temperature of the source and frequency (Miller and Thompson, 1970).

Both the total rate at which energy is emitted and the distribution of emission rate as a function of wave length depend on the body's temperature. As expressed by Planck's radiation law, the rate at which a body radiates energy increases with the fourth power of the absolute temperature; while the wavelength at which it emits most intensely varies inversely with the temperature (Hillel, 1971). In other words, hot bodies, like the sun (6000 degrees Kelvin), not only radiate much more energy per unit surface area per unit time than cool bodies like the earth, but they do so at shorter wavelengths (Miller and Thompson, 1970; Sutton, 1953).

The frequency at any point in the electromagnetic spectrum is inversely proportional to the wavelength and directly proportional to the speed of the wave motion. Since the speed is constant ($3X10^{10}$ cm/sec or 186,000 mi/sec) the relationship reduces to:

$$\text{frequency (cps)} = \frac{3X10^{10}\ \text{cm/sec}}{\text{wavelength(cm)}}$$

Henceforth, a portion of the electromagnetic spectrum will be referred to only in terms of its wavelength. Wavelength can be measured by several units, but for the purposes of this paper all

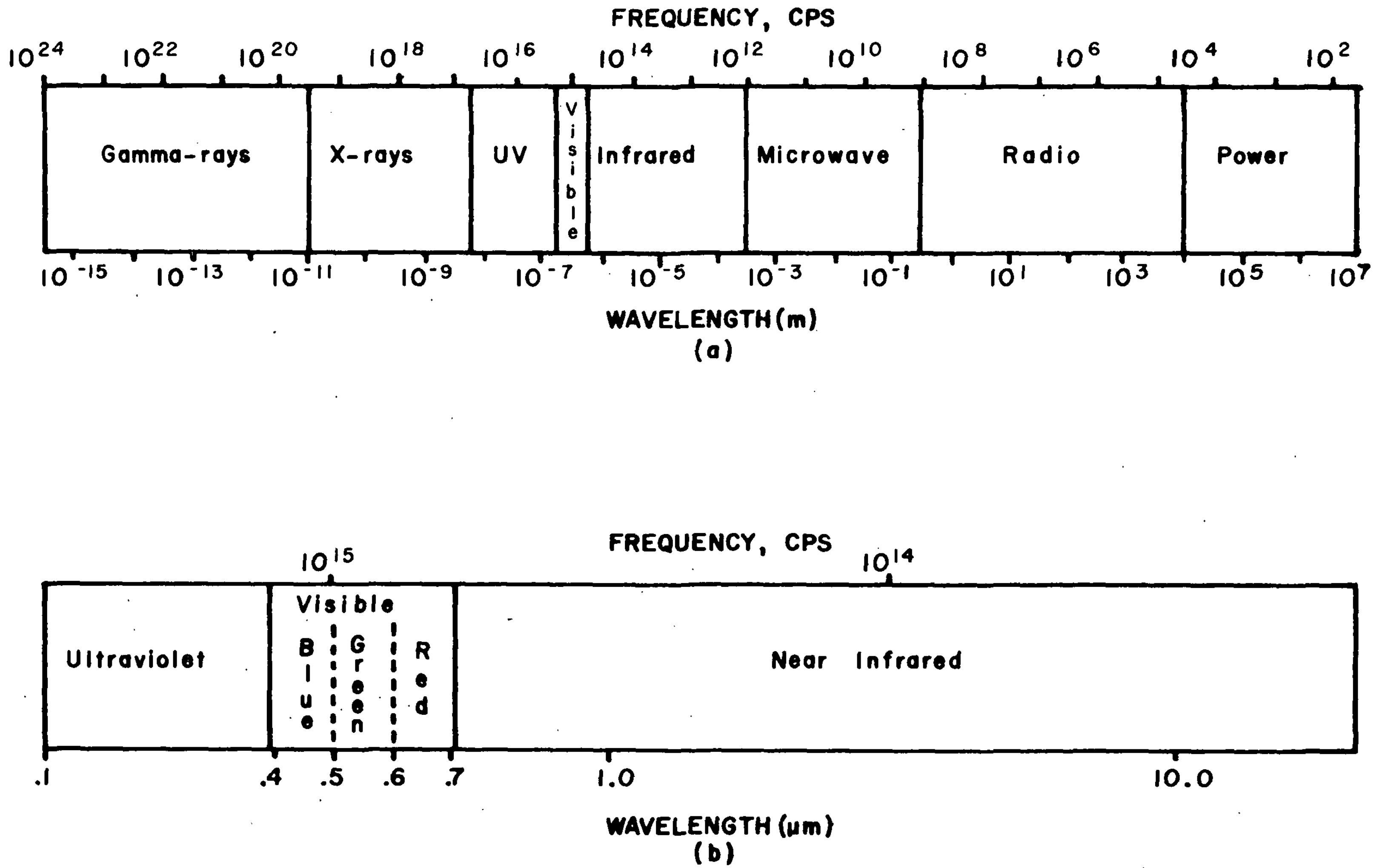


Figure 1. (a) The electromagnetic spectrum; and (b) a portion of the electromagnetic spectrum commonly associated with remote sensing measurements in agriculture.

measurements will be given as micrometers (μm) which convert to:

$$1\ \mu m = 10^{-6}\ \text{meters}$$
$$1\ \mu m = 10^{-4}\ \text{centimeters}$$
$$1\ \mu m = 10^{-3}\ \text{millimeters}$$
$$1\ \mu m = 10^{3}\ \text{angstroms}$$

Approximately 80 percent of the sun's energy falls in the visible and near-infrared portion of the spectrum with the peak energy occurring in the blue-green band (.5μm). The next section examines what happens to this enormous amount of energy as it enters the earth's atmosphere and ultimately reaches the earth (Sutton, 1953).

Radiant Energy

The average amount of solar radiation striking the outer fringe of the atmosphere is approximately 2.0 cal/cm^2/min. This radiation is selectively scattered, reflected, and absorbed as it passes through the layers of the atmosphere so that only 50 percent reaches the earth's surface where the remainder is again reflected, transmitted, and finally absorbed (Miller and Thompson, 1970; Sutton, 1953).

Molecular oxygen in the ionsophere and an ozone layer in the stratosphere absorb almost all the ultraviolet (<.32μm) radiation. Small particles and molecules deflect light with wavelengths less than their diameters causing a phenomenon referred to as scattering. Thus the blue of the sky is a consequence of a more complete

scattering, chiefly by molecules of air, of the shorter wavelengths in the insolation beam (Trewartha, 1954).

The radiant energy from the sun encounters still another obstacle before it reaches the surface of the earth--clouds. Most clouds are good reflectors and poor absorbers of radiant energy and their reflection depends on their thickness and the nature of the cloud particles. In general the earth's surface is a poor reflector of solar radiation (Miller and Thompson, 1970). It is estimated that 35 percent of the total incoming radiation is returned to space in its original form by scattering and reflection from clouds, molecules, and the earth's surface. This is known as the earth's albedo (Trewartha, 1954).

Albedo and Reflectivity

Hillel (1971) defines albedo as the reflectivity coefficient of the surface toward shortwave radiation. Reflectivity as used in the following paragraphs refers to the percent reflectance of a surface for a specific wavelength band. Both are dependent on many factors, but sun angle affects nearly all surfaces and varies with latitude, season, and time of day. Table 1 contains typical reflectance values for some common agricultural surfaces as measured by Gates and Hanks(1967).

TABLE 1. SOLAR REFLECTANCE BY SEVERAL CROPS AND SURFACES*

Crop or Surface	Reflectance (.3-2.5μm)
Soil, Silt Loam, Dry (before cultivation)	0.23
Soil, Silt Loam, Dry (after cultivation)	0.15
Soil, Clay Loam, Wet	0.11
Soil, Clay Loam, Dry	0.18
Grass	0.24 -0.26
Meadow, 18 inches high	0.25
Alfalfa	0.16 -0.22
Barley, Full cover, Boot--Maturity	0.21 -0.22
Wheat (spring)	0.14 -0.20
Wheat (winter)	0.14 -0.27
Corn, 2-7 ft. tall	0.16 -0.17
Sugar beets	0.14 -0.24
Sugar beets, ¼ to full cover	0.13 -0.29
Potatoes	0.17 -0.27

*(Gates and Hanks, 1967)

Albedo is normally measured with two pyroheliometers or a net radiometer that records an average albedo for the sensitivity range of the instrument. Measurement of reflectivity or percent reflectance at specific wavelengths requires the use of an instrument that measures reflectance constantly as it scans through a predetermined spectral range providing a spectral signature of the surface. Spectrophotometers, spectroradiometers, and multispectral scanners are used for this purpose.

Photography can be used to measure reflectivity because photographic film is sensitive to reflected radiation and can be filtered to measure discrete bands of the spectrum. The use of several cameras with different films and filters is known as multiband photography. Film with three separate layers sensitive to three

distinct bands of the spectrum is referred to as multiemulsion film and can be filtered after exposure to provide spectral response data in each of the three bands (Hoffer, Anata and Phillips, 1971).

The albedo of vegetation varies with the species and variety, relative size and maturity, leaf geometry and area, rate of transpiration, physiological stresses, rate of photosynthesis (chlorophyll absorption) and many other variables (Hoffer, Holmes and Shay, 1966).

The albedo of soil is affected by most of the properties of the surface horizon and indirectly by some of the properties of the subsurface horizon most important of which is moisture content. Spectral measurements in the laboratory of over 250 samples have shown that larger variations exist between wet and dry samples of the same soil than exist between sand and clay (Figure 2). The reflectance of the clay soils was much more readily affected by the water absorption bands at approximately 1.45 and 1.95 μm. Surface crusting limits the usefulness of reflectance data since the soil below can be quite moist (Hoffer and Johanssen, 1969).

Planet (1970), after comparing reflectance measurements of wet and dry soils, reported that the observed darkening of wet soil was due to the optical effects of a thin liquid layer on the surface and that one of the factors affecting his accuracy was the change in the physical nature of the soil surface by water.

Texture is an important factor affecting the albedo of soils. Laboratory studies had shown clay soils to have a higher reflectance than sandy soils (Bowers and Hanks, 1965), but in 1968 Myers and

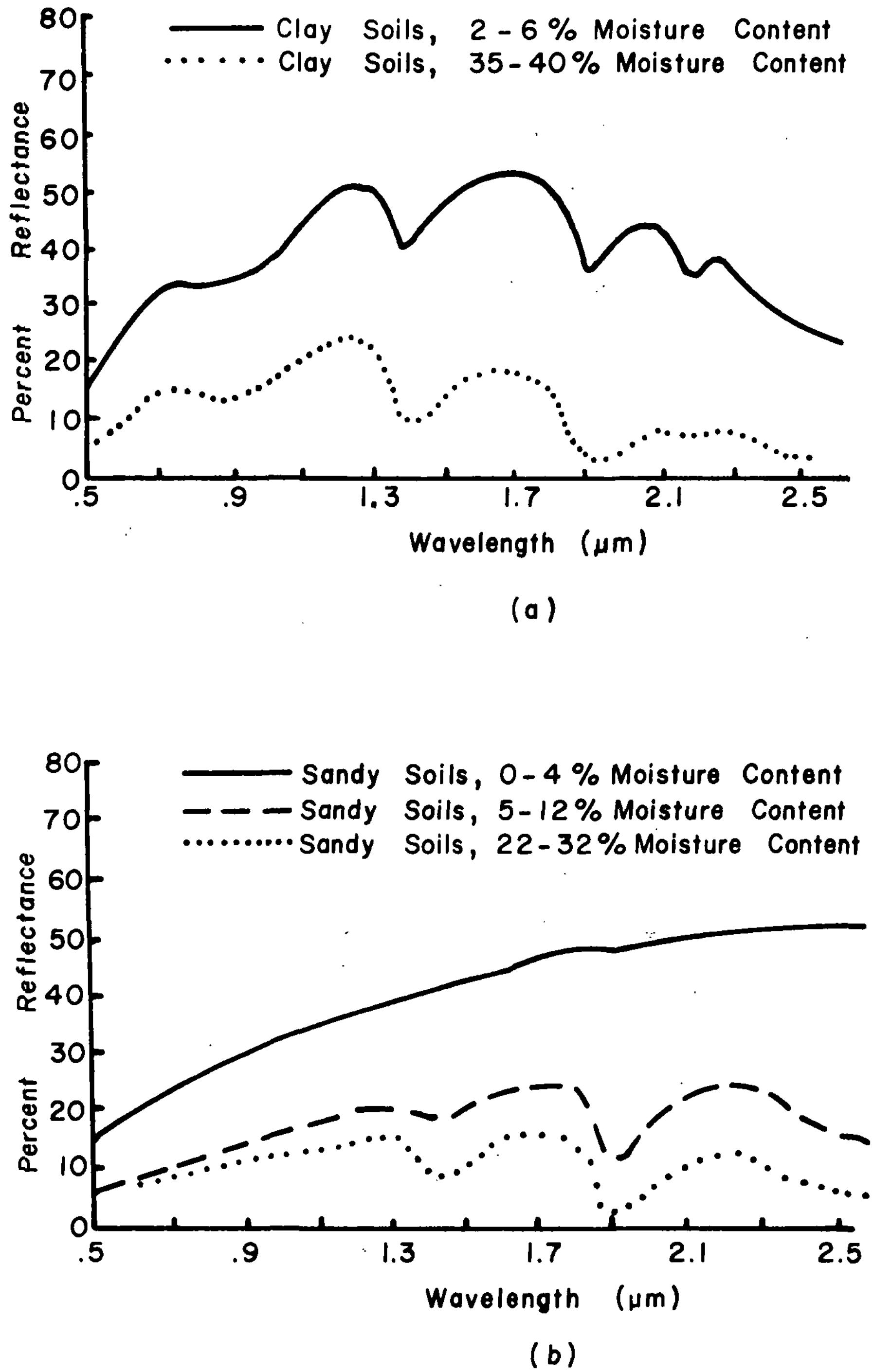


Figure 2. Reflectance curves for (a) clay soil at two moisture levels and (b) sandy soil at three moisture levels (Laboratory for Remote Sensing, 1970).

Allen reported that under field conditions undisturbed sandy soils had higher reflectances than undisturbed fine textured soils. The apparent incongruity was due to the strong influence of surface structure which gave the clay an apparent sandy texture in the field study.

Soil structure, when considered as surface structure or degree of aggregation, is a property affecting reflectance which can override differences in soil texture. Cloddy soils have a lower reflectance than granular soils because the incident radiation is reflected in many directions by the rough, heterogeneous surface (Myers and Allen, 1968).

For the same reason, surface roughness which is usually determined by tillage practices in agricultural areas affects the albedo of soils. A deep tillage practice such as plowing decreases the albedo by breaking the surface crust, increasing surface roughness, and bringing the moist subsoil to the surface (Myers and Allen, 1968).

Soil color is an important factor affecting albedo. Soil color is most commonly measured by comparison to standard color chips such as the Munsell system (Munsell Soil Color Charts). In this system a color is determined by a combination of hue, value, and chroma. Hue is the dominant spectral color, value refers to the relative lightness or tone, and chroma is the relative purity or strength Hue and chroma are wavelength dependent and therefore should provide the basis for a unique spectral signature that would allow the mapping of soils by remote sensors (Soil Survey Staff, 1951).

In 1969 Parry, Cowan, and Heginbottom found that exact correspondence between field and photo colors as defined in the Munsell system was not obtained and that very few soils provided a unique color signature at either the soil series level (USDA) or the Unified Soil Classification System group level.

Condit (1970) measured the reflectance of 160 surface soil samples from 36 states (South Dakota not included) at five wavelengths (.44, .54, .64, and .86 μm) and found that he could classify soils into three general types based on the shape of their spectral reflectance curve. Although Condit studied several wavelengths, most researchers agree that the red portion of the visible spectrum (.6 - .7 μm) provides the best results when studying soil color (Myers and Allen, 1968).

Soil color changes with moisture content and for this reason soil color is best described both dry and moist. Increased moisture usually results in decreased value and sometimes in increased chroma or change in hue (Westin et al., 1954). Most researchers agree that soils are best differentiated on the basis of soil color when the soil is dry. (T. W. Wagner, 1971. Multispectral remote sensing as a survey system for mapping soils and soil conditions, Masters Thesis. University of Michigan, Ann Arbor)

Organic matter content and mineral content also affect the reflectance of soils to a lesser degree. High organic matter generally results in darker soils and decreased reflectance (Bowers and Hanks, 1965). Similarly reflectance in the region from .5 μm to .64 μm is

inversely proportional to the iron content (Myers and Allen, 1968).

Researchers are not in complete agreement on the best time of year for measuring the reflectance of soils. Simikova (1959) found that summer and early fall were the best times to study the soils of the Steppe in Russia. Hoffer et al., (1966) in comparing a clay loam and silt loam found that reflectances were higher and more contrasting on 1 July than on 1 September. Frazee, Heil, and Westin (1971) have found that May is the best time of the year for studying soil conditions in the Lake Dakota Plain in South Dakota due to vegetation masking later in the year. The ideal time seems to depend on the properties of the soil under study, the climate and geography of the study area, and the crop calendar.

Before leaving the subject of reflectance and albedo, in summary we can say that the contrasts observed in reflectance measurements are influenced by vegetation (due to seasonal changes); moisture and surface roughness; and to a lesser degree by texture, structure, color, and organic matter content.

Concepts

The basic problem in the remote sensing of soils becomes that of using measurements of the surface of the soil taken at one or more times to make inferences about and differentiate between soils that are dynamic, three-dimensional, and often masked by vegetation or cultural practices.

The problem is not new and some of the concepts in use today are quite old, but have been refined to a high degree. As would be

expected, most of the concepts consist of analyzing an observable or measureable characteristic of the land or soil in terms of its relationship to the soil profile.

The concept of photo interpretation is the oldest, most widely used, and therefore most highly refined of the concepts used in the remote sensing of soils. Although photo interpretation has been aided by the addition of automatic enhancement devices, the analysis of photos is initially attacked by the interpreter using one of three approaches.

If the interpreter is trained in soils, geology, or geomorphology and has some experience in photo interpretation, he will probably approach the interpretation of the photography from a landform recognition standpoint. This method is based on the fact that five of the six soil forming factors are physiographic in nature and analysis and classification of these physiographic features yields probable soil boundaries. Examples of physiographic features are drainage patterns and intensity, bottomland and alluvial fans, stream terraces, ridgelines, and marsh or wetspots. This method is commonly used by resource managers and in reconnaissance surveys at small scales (Vink, 1964; Frost, 1960).

If the interpreter is more experienced in photo interpretation than in soils or geomorphology he probably will approach the interpretation as an elemental analysis of the photo characteristics of tone, pattern, shape, texture, and size. This technique involves grouping similar elements of the photo together on the basis of the

photo characteristics mentioned above. Usually this technique is necessary when working at large scales, on small areas, or with homogeneous soils on level terrain (Goosen, 1967). Using this approach poorly drained soils appearing dark in depressions may be separated from well drained soils on convex slopes, and color patterns may indicate associations of eroded and uneroded soils (Soil Survey Staff, 1966).

The third and most common approach is a combination of landform recognition and elemental analysis and will be referred to as terrain analysis. It allows the interpreter who must be experienced in both photo interpretation and soils to delineate land systems from small scale photography and to progressively subdivide these systems into smaller units of the landscape and eventually into units similar to soil series and types. This method initially uses landform recognition to delineate major divisions and then subdivides them using an elemental analysis. (R. D. Heil, 1972. Recognizability and reproductibility of airphoto interpreted soil landscape units. Ph.D. Thesis, SDSU, Brookings, S. D.)

The methods of photo interpretation mentioned above have been greatly improved and enhanced by the use of color photography. Mintzer (1967) provides a list of eleven studies which report much better results obtained from color photography as compared with panchromatic photography. He concludes, "Today it is only the most conservative photo interpreter who still uses panchromatic aerial photography alone".

Because color infrared film is well suited for studying vegetation its usefulness in soil studies has been explored by several researchers. In a study involving a comparison of color and color infrared film for identifying soil types from 12 air-dryed soils differing in Munsell color designations, the results showed color infrared distinguished best among the low chroma soils and color was best for the high chroma soils (Gerberman, Gausmann, and Weigand, 1971).

Before leaving the subject of photo interpretation, it must be emphasized that photo interpretation of soils is always done in combination with field work. The amount depends on the scale of the map, time available, and the size of the area studied; but generally sample areas selected for field checking should not exceed 15 percent of the area. This combination can generally reduce the cost of a soil survey to one fourth or one half the cost of a conventional survey (Vink, 1964).

In an experiment by the Canadian Department of Agriculture an area on the southwest coast of Vancouver Island was mapped by photo interpretation on four types of film and compared to a soil map produced the year before by field methods. The results showed that the photo interpretation was between 72 and 80 percent correct and the color film gave the best results. (Valentine et al., 1971)

In summary, the advantages of photography and photo interpretation are superior resolution, spatial correctness, ease of interpretation, and simple and inexpensive equipment. The disadvantages include the

requirement for clear weather and daylight, the possible delay for processing, and the possibility of bias in the interpretation (Heller, 1970).

The photometry concept considers the basic photo characteristic of tone which is a function of film density. This concept assumes that objects or conditions of interest will consistently appear as unique tones on imagery. These tones or densities can then be measured by spot densitometers, scanning microdensitometers, or density slicing devices. Some density slicing devices permit the color-encoding and area measurement of these density levels (Frazee, Myers, and Westin, 1972).

The end product of the photometry concept is oftentimes an isochromal (in the case of color) or isotonal map. Rib and Miles (1969), in evaluating this technique for use in terrain analysis, concluded that preparation of isochromal or isotonal maps from point readings on a grid basis was not feasible, and continuous densitometric scans were necessary. In addition, they found that differentiation of significant terrain features was not possible by isotonal mapping or from measurements of continuous scans on a single film type because several terrain features had the same density or the influences of film type, season of year, photo scale, scanning filter, aperature size and cultural features caused more variation within a given terrain feature than occurred between terrain features.

Frazee, Carey, and Westin (1972), have found density slicing techniques useful for determining composition within soil complexes

and in delineating soil limitations and range sites. By interacting with the density slicing device improved soil maps were produced.

The spectral signature concept is a parametric approach in that it evaluates a single attribute and determines its spectral signature from a study of its variability at one or more wavelengths and under various conditions. This concept eliminates the subjectivity of other approaches and achieves a more precise definition of quantities measured (Wagner, 1971, M. S. Thesis).

Spectral signatures can be obtained and studied with spectrophotometers, spectroradiometers, filtered photography and multispectral scanners. The principle behind the multispectral approach was defined by Wagner from the University of Michigan. Wagner states, "by collecting information in a number of spectral bands and by knowing or discovering the unique spectral characteristics of objects or conditions of interest, it is possible to identify these objects or conditions and to distinquish one from another" (Wagner, 1971, M.S. Thesis).

In his thesis work conducted over a .75 mile by 15 mile rectangular area in northeastern Kansas, Wagner mapped the distribution of several classes of fluvial and upland bare soils by recording reflectance in ten spectral bands from .4 - .85 μm. He concluded that the multispectral technique was useful under the following conditions:

1. large percentage of bare soil
2. time of flight close to solar noon and parallel to solar direction

3. level terrain

4. dry soil

5. a priori information for establishing training sets

Piech and Walker (1972) from Cornell have found a technique for determining whether tonal differences on photographs are due to soil moisture or soil texture. The technique requires interpretation of soil element reflectance ratios in red and blue spectral bands. When the reflectance ratio of the darker soil element to the lighter soil element is greater in the red than in the blue, the tonal variation is caused principally by moisture. When the red ratio is less than the blue ratio, the soil elements differ due to texture. Similar work at Purdue by Baumgardner (1971) has shown that the ratio between the relative reflectance values of visible and infrared radiation is a good indicator of the percent of the ground covered by vegetation.

Pattern recognition is a quantitative approach to the analysis of spectral data that involves the computer classification of multispectral data. The quantized spectral data can be obtained directly from a multispectral scanner or can be obtained by digitizing film data with a scanning densitometer. The digital data is stored on magnetic tape for subsequent processing by the computer. The pattern recognition technique consists of calculating a vector for each point based on the multispectral data for that point. The vectors are then classified based on training sets from sample areas or by a clustering technique whereby the number of classes is designated by the

analyst (Kristof, 1971; Hoffer et al., 1971).

The classification results can be a computer printout in tabular or map form or a display. Researchers at Purdue have been very successful in classifying crops and soils using the pattern recognition approach on data from multispectral scanners and multiband and multiemulsion photography, but emphasize that this technique is a powerful and useful tool only as a supplement to manual photo interpretation methods (Kristof, 1971; Hoffer et al., 1971).

Conclusions

From a review of the literature several conclusions were drawn. Initially, laboratory results often do not hold true in the field. Soil, because it is dynamic, must be studied in its natural environment. Similarly, reflectance measurements recorded at ground level, are often degraded, lost, or even reversed, by increased altitude and decreased scale.

Secondly, previous studies have fallen short due to lack of ground truth for comparison or verification purposes. Wagner, in his thesis, reported that he was hampered because he did not have adequate information for training the computer to recognize the tones that corresponded to soil differences. Similarly, other investigators have resorted to comparing their imagery or isotonal maps to mapping units or cartographic units on published soil surveys. A correspondence between the two is decreased by the fact that the map units contain inclusions of other units and are based on soil properties that may not be measured by the sensor in use. The ground truth

must include measurements of the properties of the soil that are capable of being detected by the sensor.

Finally, more information is needed on which soil properties and combinations of properties are responsible for the anomolies we detect with remote sensors. To be of any practical value we need to be able to do more than divide soils into some arbitrary number of categories. The classification must be based on one or more properties of the soil for this classification to be useful in estimating the soils capabilities or limitations. Studies in the past have concentrated on properties of the soil surface such as organic matter content, texture, structure and roughness, moisture content, and temperature. Although somewhat empirical in nature, a study comparing some of the soils subsurface and genetic characteristics to properties at the surface could provide valuable information pertaining to the detection of soil limitations.

MATERIALS AND METHODS

The Approach

The classification of soils based on their limitations to crop growth has been recognized as a useful system for many years. Previous work (Westin et al., 1954) had shown the main soil limitation to crop growth in the proposed Oahe irrigation project was the existence of a natric horizon or claypan in the rooting zone which decreased internal drainage and resulted in ponding and slow infiltration of water. An erosion limitation also existed where the degree and length of slope were sufficient to permit the detachment and transport of the surface horizon.

The remote detection of soil limitations required an understanding of the relationship between the soil and the tonal variation observed on photographic film. To study this relationship a field typical of each soil limitation was selected from a flight line crossing the Oahe project. Field data was collected during the summer of 1972 for comparison with imagery obtained the year before. A description of the study area and the data collection and analysis methods follows.

Description of Study Area

The study was conducted on a flight line eighteen miles long and two miles wide north of Redfield, in Spink County, South Dakota (Figures 3 and 4). The area was selected because it contains several soil series, three main physiographic divisions, and an area that is

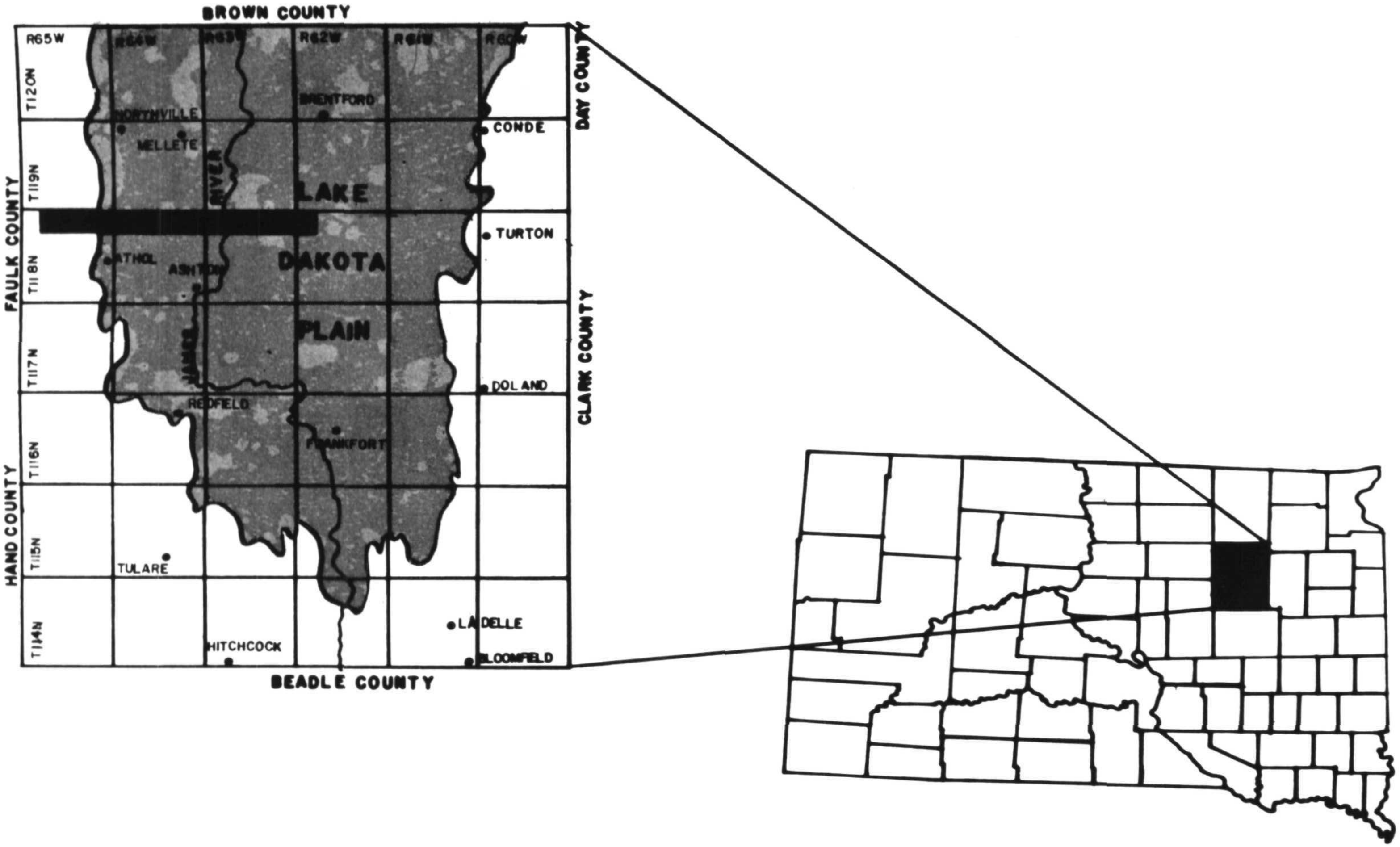
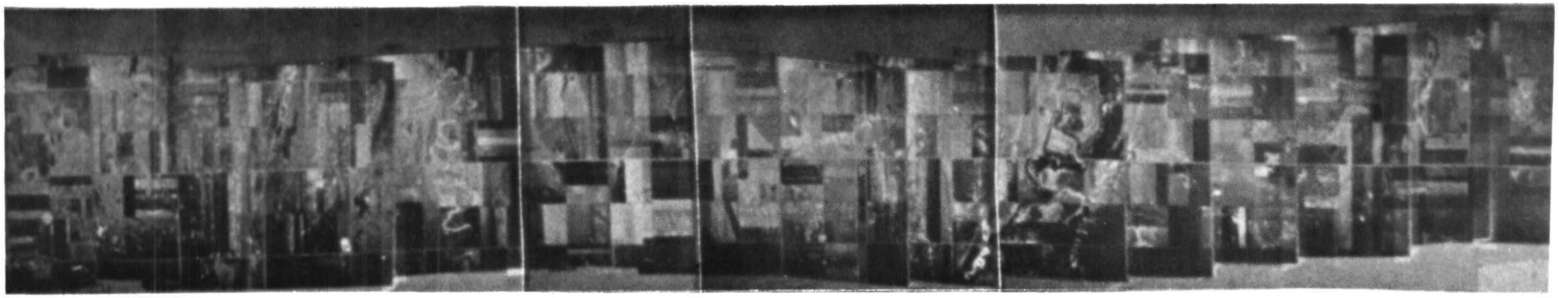
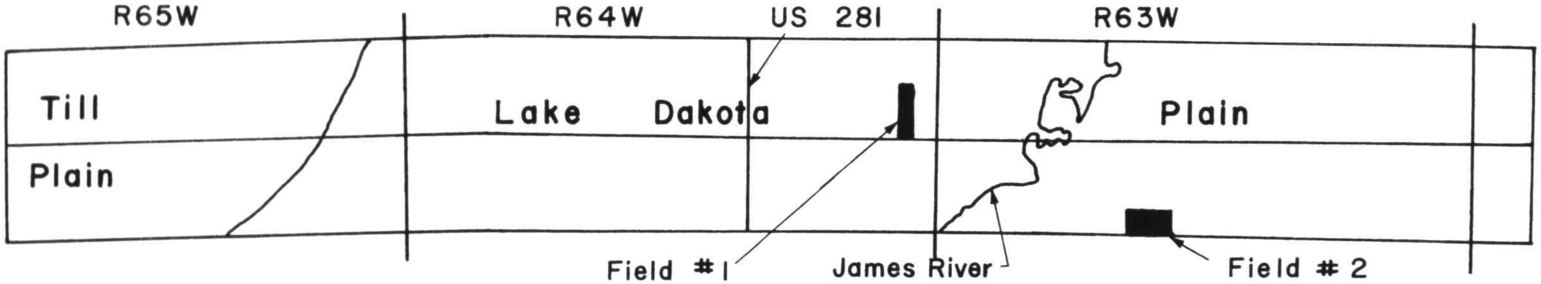


Figure 3. Location of flight line in Spink County, South Dakota.



(a)



(b)

Figure 4. (a) Mosaic of the flight line from color infrared photographs for May 14, 1971; and (b) Schematic showing the location of study areas.

scheduled for irrigation in the near future by the Oahe Irrigation Project. Spring wheat is the major crop in the area although winter wheat, barley, oats, rye, sorghum, and corn are grown. The remainder of the land is used for pasture and hayland for the beef cattle that are produced.

The climate of the region can be described as a sub-humid, continental, microthermal climate with warm summers and cold winters. The average annual precipitation of 48.8 cm and the high rate of evapotranspiration results in a climate that is very nearly semiarid. Local weather is exemplified by extreme variations in temperature, high winds and hail, and drought spells (Westin et al., 1954).

Prior to settlement, the region was covered by short, mid and tall grasses such as big bluestem, little bluestem, blue grama, and western wheatgrass. Trees were confined to river valleys and stream banks where moisture was adequate (Westin et al., 1954).

The bulk of the study area is situated on the bed of Glacial Lake Dakota which was formed by meltwater from the retreating glacier some 10,000 years ago. The area also transects the floodplain and terraces of the James River which drains the Lake Dakota Plain. The west end of the flight line spans the shoreline of the glacial lake and onto the till plain created by the Cary stage of the Wisconsin Glacier (Flint, 1955).

The nearly level topography of the lake plain is interrupted only by the James River and the channels of a few shallow streams. Because surface drainage is poor and the medium-fine textured

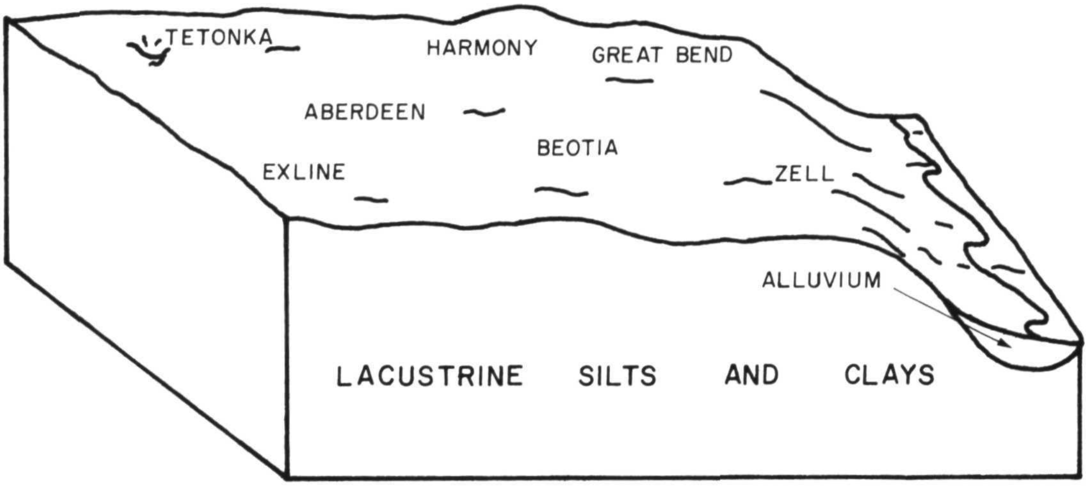
lacustrine parent materials are slowly permeable, ponding is extensive in the spring and early summer. This ponding and subsequent evaporation along with the chemical properties of the parent material have been largely responsible for the formation of the claypan soils that are typical of this area. A typical catena for the lake plain finds the Tetonka soils occupying the depressions; the Exline, Aberdeen, and the Harmony soils on the level positions; and the Beotia, Great Bend and Zell soils occurring with increasing slope (Figure 5). The claypan of the Exline, Aberdeen, and the Harmony soils is the principal soil limitation of the area. An erosion limitation exists on the steeper slopes of the Zell and Great Bend soils; and the Tetonka soils have a wetness limitation.

Field Data

Two types of field data were taken during the course of the project. The first type included the standard information on crop and soil conditions taken at the time of flight and the information gleaned from weather records and soil surveys. A tabulation of existing crop, soil, and field conditions on May 14, 1971 is presented as Table 2.

TABLE 2. FIELD CONDITIONS ON MAY 14, 1971

	Field #1	Field #2
Crop Type	Oats	Winter Wheat
Crop Height	20 cm	50 cm
Row Spacing	15 cm	25 cm
Crop Residue	Little	Little
Weediness	Clean	Slight
Surface Roughness	Smooth	Smooth
Surface Moisture	Adequate	Adequate



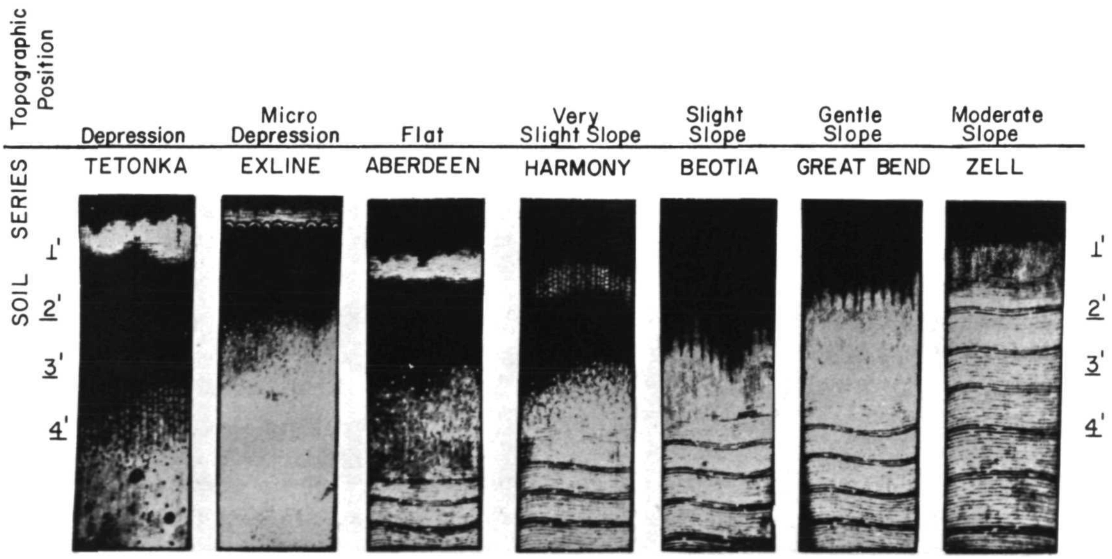
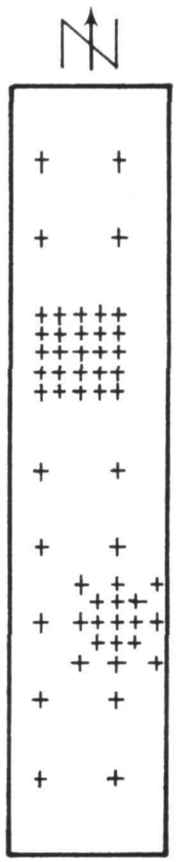


Figure 5. Topographic relationships of soils (after Westin, 1970).

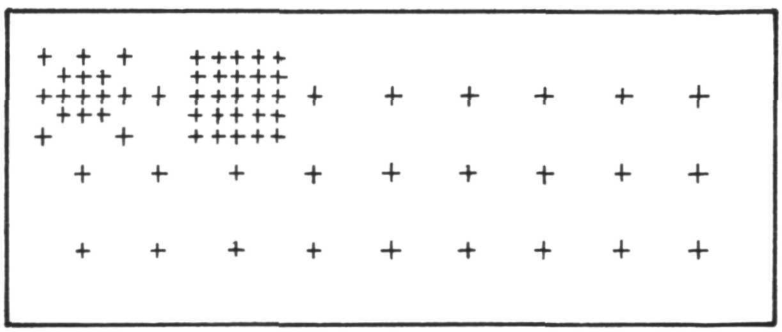
The fields studied were selected under three criteria. They had to be accessible with the probe truck, contain typical examples of claypan or erosion limitations, and exhibit tonal contrast on the 1971 imagery. The first criteria limited the selection to fields that were in fallow during the 1972 growing season. Two fields were selected as representative. Field #1 was a 14 hectare field with an erosion limitation and Field #2 was a 32 hectare field with a claypan limitation. For all practical purposes the fields were essentially bare soil with little trash or weeds to disrupt the detection of soil differences at the time of flight.

The second type of field data was the observations and measurements made at the grid points. The grid was initially layed out at 80 meter intervals with steel tape and a surveying instrument. A level traverse was then run to determine the elevation of each point. Within each grid two grid squares were selected for detailed study and the sampling density was increased 16-fold. These squares were selected by a stratification procedure based on photographic tone with the objective of determining the variation within the stratified sample. Figure 6 shows the grid layout.

The same observations and measurements of the soil surface and the soil profile were made at all grid points within the same field. Core samples of the soil profile were obtained with a 2-inch probe mounted on the back of a pickup truck. The probe permitted the observation and description of the profile in a nearly undisturbed condition. For each core, the depth, Munsell color, texture, structure, consistence,



FIELD #1



FIELD #2

Figure 6. Grid layout for Field #1 and Field #2. Scale=1:7920.

and reaction of each genetic horizon were recorded. In addition the depth to carbonates was determined using a .1N HCl solution and the slope, aspect, position, and drainage class of the site were noted.

To obtain an estimate of the reflectivity of the soils studied under field conditions measurements were made on August 10 and 11 with an ISCO Model SR spectroradiometer. Reflectivity in the red band of the spectrum (.6 μm) was determined by directing the remote probe straight down from a height of 15 cm to measure the reflected radiation and then inverting it to measure the incoming radiation. The same procedure was repeated at several locations within the fields to measure the difference in reflectivity due to erosion and claypan limitations.

In addition to determining the reflectivity and color of the surface soil under field conditions, an estimate of the reflectivity and Munsell value was obtained in the laboratory under controlled conditions by the use of an ISCO Model SR spectroradiometer and Munsell color charts. The surface samples were oven-dried and ground to pass a 100-mesh screen. The sample was then placed in a shallow pan that had been painted flat black to reduce its reflectivity. The pan was placed under a light source consisting of fluorescent lamps which peaked at .58 μm. The remote probe attachment of the ISCO spectroradiometer was positioned 10 cm above the pan for the reflectance measurement and was inverted to measure the intensity of the incoming radiation. The ratio of the reflected to the incoming radiation provided an estimate of the soil's reflectivity. Reflectivity at

.58 μm was computed for all surface soil samples for comparison with film transmittance data.

A soil sample was taken of the plow layer minus the surface trash at each point for laboratory determination of organic matter content. Organic matter content was determined at the South Dakota State University Soil Testing Laboratory by the potassium dichromate and sulfuric acid digestion method utilizing a colorimeter, and was reported as percent readily oxidizable organic matter.

In addition to the surface samples, clod samples of the B horizon were obtained in Field #2 to verify the location of claypans. Air-dry bulk densities were determined in the laboratory by coating the clods with paraffin and suspending them in water to determine their volume. Air-dry bulk density was calculated from the following formula:

$$\text{Bulk Density (Air-Dry)} = \frac{\text{Air-Dry Wt. of Clod}}{\text{Wt. of Waxed Clod in Water}}$$

Subsequent oven drying of duplicate clods revealed the presence of only a small amount of water in the air-dry samples (5-6% by wt). A tabulation of the soil properties measured and observed at each site and a sample of the form used are contained in Appendix B.

In summary, two fields were sampled. Field #1 was selected because it was accessible and contained both eroded and uneroded soil. Fifty-five soil profiles were examined, sampled and measured for characteristics associated with eroded soils. Field #2 was selected because it was accessible and contained both a claypan limitation and normal soil. Sixty-seven soil profiles were evaluated and sampled for

properties characteristic of claypans. The ground truth portion of the experiment proved to be tedious and time consuming, but nevertheless necessary to provide the detailed soil information for subsequent comparison and correlation with film data.

Aerial Data

Although several missions were flown during the 1971 growing season, the imagery from the May mission had the best tonal contrast indicative of soil differences and was selected for detailed analysis. The May mission was planned to coincide with a period of maximum bare soil, but the exact day of flight was determined by the daily weather since a dry surface and clear sky were considered prerequisites.

Three flightlines were established along the length of the study area. Line #5 was centered on the study area and at 3050 meters altitude provided complete coverage at a scale of approximately 1:62,500. Lines #3 and #4 were centered on the south and north halves of the study area respectively. At 2440 meters altitude the photography from these lines provided coverage at a scale of approximately 1:50,000. The altitudes and photoscales used provided adequate coverage of the area without using the portion of the photograph near the edge of the frame where vignetting and sun angle presented some problem.

The imagery used in this project was obtained by the Remote Sensing Institute aircraft on May 14, 1971. The mission utilized a four-camera, 70 mm Hasselblad setup containing four different film/filter combinations to record in the visible and near-infrared regions

of the spectrum. The band pass filters only transmitted light within the wave length range of the filter. The four-camera set up was used to allow comparisons that would determine the best spectral range for detecting soil limitations. In addition a thermal scanner was used to measure emitted radiation in the infrared portion of the spectrum and a precision radiation thermometer provided a reference temperature for the calibration of the thermal scanner imagery. A recording solameter on the top of the aircraft measured total incoming radiation and three filtered solameters on the bottom of the aircraft recorded changes in reflected radiation on a paper chart recorder.

The mission was conducted at approximately midday under clear sky conditions. Exposure time and lens opening were adjusted by the camera-man to obtain the best possible picture under the existing ground conditions. All phases of the processing and developing of the film were held as constant as possible. The thermal scanner was operated at 4.5 - 5.5 μm during the mission and the infrared anamolies were printed automatically on a 70 mm filmstrip for future interpretation and analysis. A list of the sensors used and conditions at the time of flight is provided in the Appendices.

Visual Analysis

The large amount of data gathered was initially evaluated as to its quality and usefulness with reference to the specific objectives of the project. Limitations with regard to time and personnel were also taken into consideration. The measurements and observations noted on the field sheets were evaluated with reference to their

relation to the soil limitations under study. The parameters selected for evaluation were then coded and placed on computer cards. A similar procedure was followed in evaluating the aerial data obtained from the sensor package employed. The data from the thermal scanner, the solameters, and the positive radiation thermometer were evaluated in reference to their usefulness and quality. The photographic data from each of the four 70 mm Hasselblad cameras were also evaluated for quality and contrast.

Digital Analysis

As in other research efforts, the demand for a method of quantifying the data became apparent when presented with the problem of comparing the field data with the film data. The solution was to quantify the film data, code the field data, and make a point by point comparison utilizing a correlation/regression analysis.

The task of quantifying the film data was accomplished with the Signal Analysis and Dissemination Equipment (SADE) installed at the Remote Sensing Institute (Appendix A). The systems high resolution image digitizer, utilizing an image dissector tube, permitted the digitization of the imagery into 256 levels (output codes) at a resolution of 36 pixels per millimeter. Each pixel or resolution element represented approximately two square meters on the ground.

The light level was optimized for the density range of the film and the digitization process was conducted for the film without a filter (neutral) and repeated for each filter (red, green and blue). The red filter measured the infrared-sensitive layer on the film, the green

filter measured the layer sensitive to the red band, and the blue filter measured the layer sensitive to the green band. The light level was adjusted for each filter to compensate for adsorption by the filter. The digital data was stored on tape and subsequently printed on computer paper providing the researcher with four digital maps of output codes (0-255) for each field. The high resolution of the image digitizer allowed 75,000 measurements within the 4 x 16 mm image of Field #1 and 175,000 measurements of Field #2 (8 x 16 mm) for each filter. Frequency distributions of the output codes from each filter were determined and plotted.

The locations of the ground truth observation points were plotted on the computer maps and an average value for the corresponding output codes was determined by averaging the values of four or five of the adjacent output codes to reduce the effects of random error. Output codes for all of the grid points from each of the computer maps for each of the fields were obtained in this manner, and subsequently used in the correlation/regression analysis. In addition to the computer map output the digitized data was displayed on the television monitor of the SADE system in eight gray levels and color-encoded into eight colors for comparison to the computer map. Each gray level or color corresponded to an increment containing 32 output codes (e.g. blue = 0-31).

The statistical analysis of the field data and the digital output codes utilized a standard linear correlation/regression computer program. All of the variables were correlated with each other to

determine the degree to which they varied together or clustered about the regression line. Correlation coefficients approaching unity indicated a significant similarity or relationship between variables. Linear regression indicated cause and effect and permitted prediction and extrapolation from known data. The field data was considered the dependent variable because in practice it was desired to predict soil properties from film data.

Pattern Recognition

The numbers generated during the digital analysis were used to classify each field into two classes based on soil limitations. Areas typical of eroded and noneroded soil were selected in Field #1 based on the results of the digital analysis. Similarly an area containing a claypan limitation and an area typical of the normal soil were selected in Field #2. The sample areas containing from 200 to 400 pixels were used for training the classifier. The K-Class classifier used was developed by Zagalsky and made decisions based on the means and variances of the sample data. The classifier was tested on the sample areas using all 16 combinations of the four features (filters) to determine which combination provided the greatest accuracy (N. Zagalsky, "A New Formulation of a Classification Procedure" M.S. Thesis, University of Minn., March, 1968).

The transmittance data for each field was then classified using all four features (NRGB) and the results were printed on computer paper and displayed. The resulting map was compared to the ground truth by plotting the ground truth points on the computer map, visually

determining the class into which each of the points fell, and subsequently calculating the mean, standard deviation, and variance for each soil property in each class. The means of the two classes were then tested for significance using the F-test from the analysis of variance. The analysis of variance table is shown in Table 3.

TABLE 3. ANALYSIS OF VARIANCE

Source	df	Sum of Squares	Mean Square	F
Between Classes (C_1vsC_2)	C-1	TSS-WithinSS	$\frac{\text{TSS-WithinSS}}{\text{C-1}}$	$\frac{\text{Between MS}}{\text{Within MS}}$
Within Classes (C_1+C_2)	$(n_1-1)+(n_2-1)$	$\Sigma x_1^2+\Sigma x_2^2$	$\frac{\Sigma x_1^2+\Sigma x_2^2}{(n_1-1)+(n_2-1)}$	
Total	n_1+n_2-1	x^2		

Density Slicing

After completion of the digital analysis and the computer classification, the same imagery was subjected to a density slicing analysis utilizing the Spatial Data system. A description of the system is provided in Appendix A. The analysis provided a check to determine the validity of the density slicing techniques used in the past (Frazee et al., 1971) and permitted the establishment of some new procedures for use in conjunction with SADE. Initially the controls of the Spatial Data system were adjusted to portray a two-color representation of the field and each color was then adjusted until it was the same percent of the field as determined by computer

classification. The procedure provided a check to determine whether the results from pattern recognition could be approximated with Spatial Data.

A second approach was the duplication of procedures used in the past which required the operator to adjust the controls to the best representation without field data for comparison. This method emphasized the ability of the operator to make sound decisions based on his knowledge of the soils of the area and his skill in photo interpretation.

A third approach employed was envisaged as a way that Spatial Data could be used to extrapolate from sample areas. The operator adjusted the light intensity and the setup controls to obtain the maximum range of densities in the black and white mode. All 32 buttons were then depressed, the display was switched to color, and both ends of the range were adjusted so that all 32 colors were displayed without any black visible on the screen. The operator then compared the display of the sample area to the field data from the sample area and determined which color or colors coincided with the areal extent of the soil condition or limitation of interest. The selected colors were then blacked out or displayed in white and the percent area was measured by the automatic planimeter. The display was photographed and the photograph was enlarged to the desired scale resulting in a map of the field.

RESULTS AND DISCUSSION

Visual Analysis

The soil limitations studied were defined on the basis of the physical characteristics of the soil. The erosion limitation was characterized by a shallow depth of carbonates (<15 cm) and a low organic matter content (<2%) resulting in a light-colored surface soil. The claypan limitation was defined as a subsurface layer of high bulk density (>1.5 g/cm^3) at a depth within the rooting zone of most plants (<30 cm). Data was collected for the properties mentioned above and for the surface properties of the soil that could be measured remotely to determine the relationship between them.

A preliminary analysis of the field data resulted in the selection of ten variables considered descriptive of the erosion limitation in Field #1, surface reflectivity, Munsell value (dry), organic matter content, depth to CO_3 (cm), percent slope, depth of the A horizon (cm), depth of the C horizon (cm), topographic position (valley, concave slope, convex slope, or hilltop), elevation, and aspect. The variables selected as descriptive of the claypan limitation in Field #2 were bulk density of the B horizon, organic matter content, depth to the B horizon (cm), surface reflectivity (dry), thickness of the B horizon (cm), and depth of CO_3 (cm). Munsell value of the surface was not selected in Field #2 because the variation was within one color chip. Such properties as texture and consistence were not selected because there was not enough variation between samples or the property was not related to

the problem.

The data from the field study using the spectroradiometer (Table 4) indicated a much higher reflectivity from the eroded soil than from the uneroded soil. The reflectivity difference between claypan and nonclaypan soils was slight, partly because the claypan soils were cloddy at the surface and the resulting decrease in reflectivity cancelled the increase due to the lighter color of the surface. The results of the field spectroradiometer study were considered inconclusive.

An evaluation of the aerial data showed the thermal scanner data was of poor quality and the low resolution of the solameters and precision radiation thermometer provided little information for the detailed analysis conducted.

TABLE 4. SPECTRORADIOMETER FIELD STUDY OF SOIL LIMITATIONS

Date (1972)	Time CDT	Location Field	Site	Incoming Radiation* IR	Reflected Radiation* RR	Reflectivity RR/IR (Percent)
10 Aug.	1545	1	Eroded	4600	400	9
	1530		Normal	4600	350	8
11 Aug.	1300	1	Eroded	5200	650	12
	1315		Normal	5150	355	7
11 Aug.	1200	2	Claypan	4900	370	8
	1215		Normal	4900	375	8

*Scale reading from spectroradiometer at .6 μm

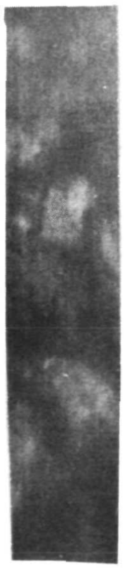
Imagery from the four Hasselblad cameras were evaluated for observable contrasts within the fields under study. A comparison of the four films showed that the black and white films with the red filter (2402-25A) had the greatest contrast and the widest tonal range, but the black and white film with the green filter (2402-58) seemed to contain the middle range of densities making it more aesthetic to view. The black and white infrared film (2424-89B) did not contain any more information than the other black and white films, except that a weedy area in the west end of Field #2 providing some infrared reflectance resulted in light tones as opposed to dark tones on the other films. The color infrared film (2443-G15/30M) was easiest to view and contained the most information. Because the film is made up of three layers sensitive to green, red and infrared radiation, the film can be filtered to yield information in each of the bands without regard for differences in processing and exposure setting that must be considered when using more than one type of film. Expedience and the demonstrated superiority of color infrared film in other work (Frazee et al., 1972) resulted in its selection for subsequent digital and density slicing analyses. A comparison of the four film/filter combinations for Fields #1 and #2 is provided in Figures 7 and 8.

Digital Analysis

The analysis was designed to evaluate only the influences of the variables selected, (depth of carbonates, organic matter content, bulk density of the "B", Munsell value, surface reflectivity, depths of the genetic horizons, and photographic tone) and therefore no inferences

FILM 2402
FILTER 58

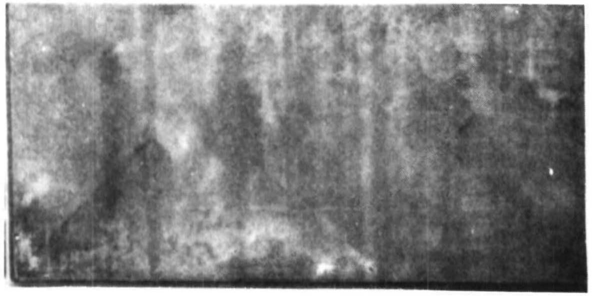
FILM 2402
FILTER 25A



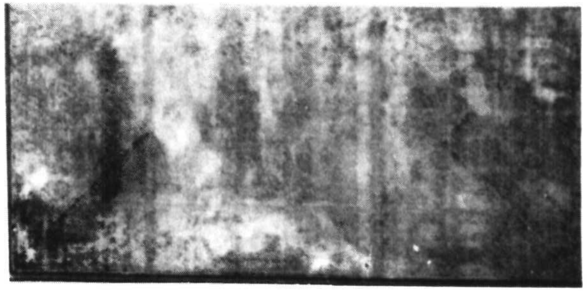
FILM 2424
FILTER 89B

FILM 2443
FILTER G15/30M

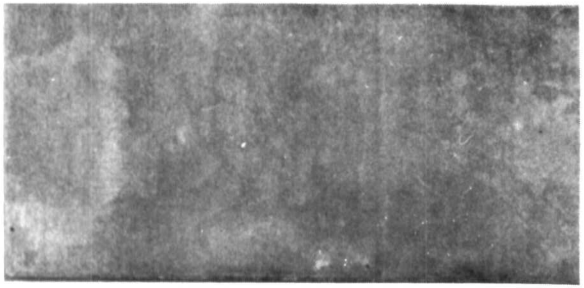
Figure 7. Photography of Field #1 on May 14, 1971. Scale=1:10,500.



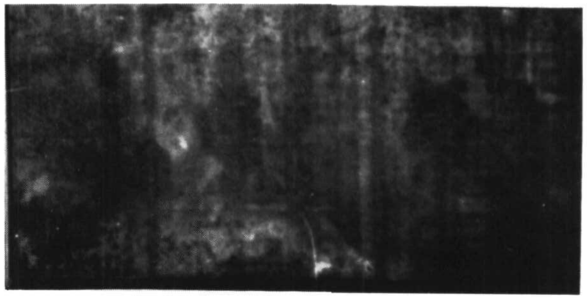
FILM 2402
FILTER 58



FILM 2402
FILTER 25A



FILM 2424
FILTER 89B



FILM 2443
FILTER G15/30M

Figure 8. Photography of Field #2 on May 14, 1971. Scale=1:10,500.

concerning other factors can be made from the results. The factors studied were selected based on their descriptive relationship to the erosion and claypan limitations. The results for each field are summarized in the following paragraphs.

Four different measurements of film transmittance corresponding to four spectral bands were obtained from the digitization of the color infrared film with the SADE system. The frequency distribution of the output codes (0-255) from the high resolution digitizer are presented in Figures 9 and 10. The high frequency on the extreme left of each of the histograms was due to the mask that marked the edge of the field and was not indicative of the soil within the field. The histograms indicated a normal distribution of output codes in all four instances. The digitized film data was also displayed on the monitor of the SADE system in eight levels of 32 output codes each. Figure 11 shows the SADE display of Fields #1 and #2 for the unfiltered film data.

The areal extent of the erosion limitation in Field #1 was determined by a shallow depth to carbonates (15 cm) and low organic matter content (<2%). The results of the correlation analysis of the field data shown in Table 5 revealed that these two properties were highly correlated with depth of the A horizon, depth to the C horizon, the value component of Munsell color, reflectivity of the surface soil, percent slope, and topographic position. The transmittance data (output codes) in all four spectral bands were highly correlated with all of these variables, but the highest correlations were with the reflectivity

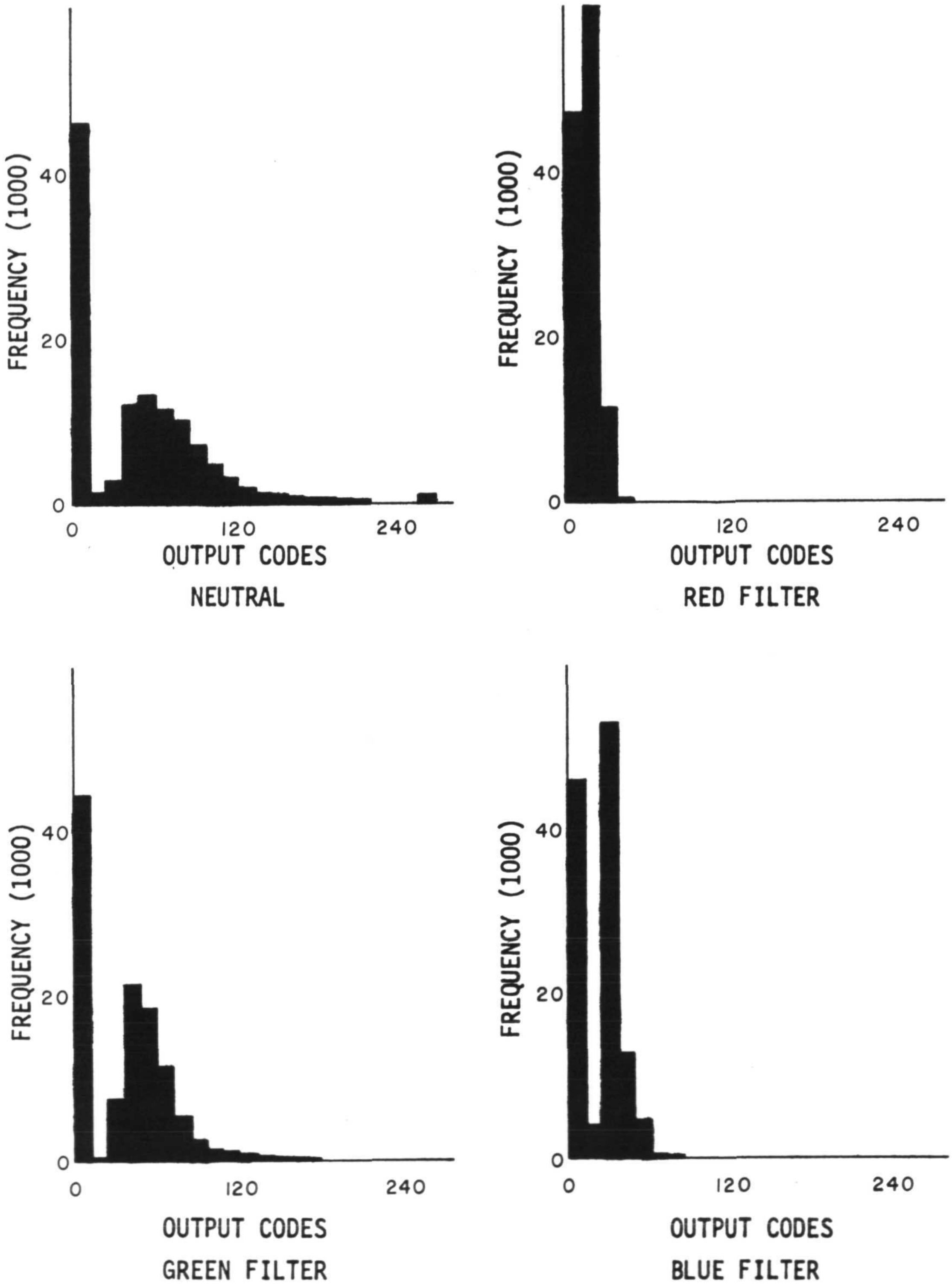


Figure 9. Frequency distributions of film transmittance data from color infrared film for Field #1.

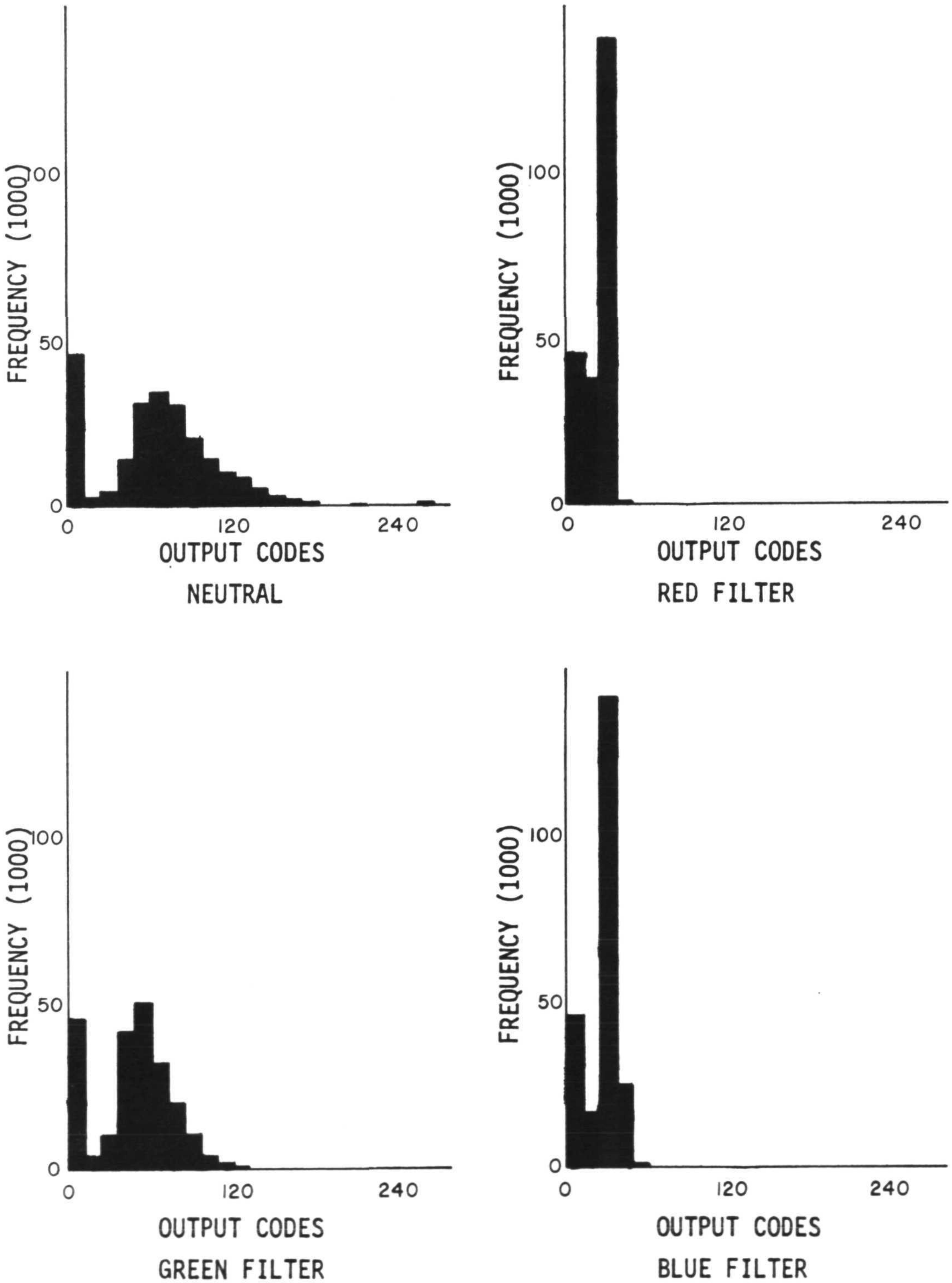
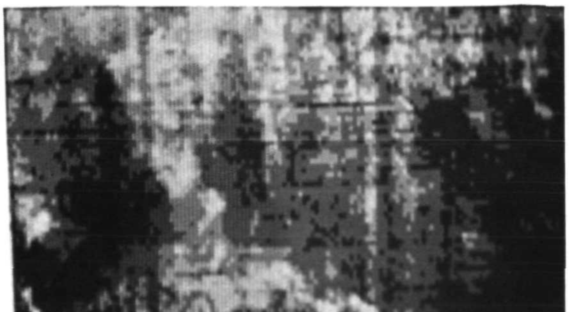


Figure 10. Frequency distributions of film transmittance data from color infrared film for Field #2.

FIELD #1



FIELD #2

Figure 11. Display from SADE of digitized image. Scale=1:10,500.

TABLE 5. CORRELATION COEFFICIENTS FOR FIELD #1

	Depth to CO_3	Depth of A	Depth of C	Elev-ation	Value	Refl.†	O.M.+	Slope	Posi-tion	Aspect	Neutral	Red	Green	Blue
Depth to CO_3	1.00**													
Depth of A	.502**	1.00**												
Depth of C	.855**	.570**	1.00**											
Elevation	-.300*	-.202**	-.358**	1.00**										
Value	-.672**	-.326*	-.582**	.296*	1.00**									
Refl.†	-.717**	-.330*	-.669**	.357**	.865**	1.00**								
Organic Matter+	.635**	.376**	.646**	-.273*	-.690**	-.795**	1.00**							
Slope	-.477**	-.361**	-.514**	.210	.428**	.485**	-.613**	1.00**						
Position	.505**	.372**	.549**	-.738**	-.314*	-.413**	.394**	-.242	1.00**					
Aspect	.309**	.267*	.347**	-.257	-.304*	-.303*	.272*	-.424**	.170	1.00**				
Neutral	-.580**	-.364**	-.569**	.232	.690**	.823**	-.716**	.474**	-.321**	-.111	1.00**			
Red	-.553**	-.331*	-.540**	.237	.637**	.767**	-.668**	.380**	-.312*	-.518**	.955**	1.00**		
Green	-.598**	-.376**	-.579**	.220	.689**	.809**	-.697**	.445**	-.318*	-.140	.978**	.913**	1.00**	
Blue	-.547**	-.285**	-.563**	.232	.676**	.801**	-.669**	.429**	-.312*	-.154	.950**	.869**	.960**	1.00**

* - significant at .05 level with 54/d.f. (>.264)
** - significant at .01 level with 54/d.f. (>.342)
† - reflectivity at .58 μm
\+ - organic matter content

values. The correlations can be explained in physical terms by the increased reflectance of the surface soil on sloping topographic position due to the exposure or incorporation by cultivation of the light-colored parent material. The light-colored C horizon has lower organic matter content (<1% vs >2%), higher Munsell value (>6 vs <5 dry), and higher reflectivity (>10% vs <7%) than the surface.

The unfiltered data had the highest correlation coefficients and the green filter was the next highest suggesting that the best spectral range for study was the red band of the spectrum. The red filter had the lowest correlation coefficients and those from the blue-filtered data were only a little higher.

Linear regression analysis of the four most highly correlated soil variables (Figure 12) indicated that as the unfiltered output codes increased (lighter tones) depth to CO_3 and organic matter content decreased, but surface reflectance and Munsell value increased. From a physical standpoint the film was actually measuring the difference in surface reflectance which in turn was highly correlated with soil color (value), depth to CO_3, and organic matter content.

The results of the correlation/regression analysis of Field #2 are summarized in Table 6 and Figure 13. For the detection of the claypan limitation the results from correlation analysis showed that the soil properties indicative of the claypan limitations (high bulk density and shallow depth to the B horizon) are highly correlated with photographic tone in all four spectral bands. This can be explained by increased reflectance of the surface horizon due to mixing of the

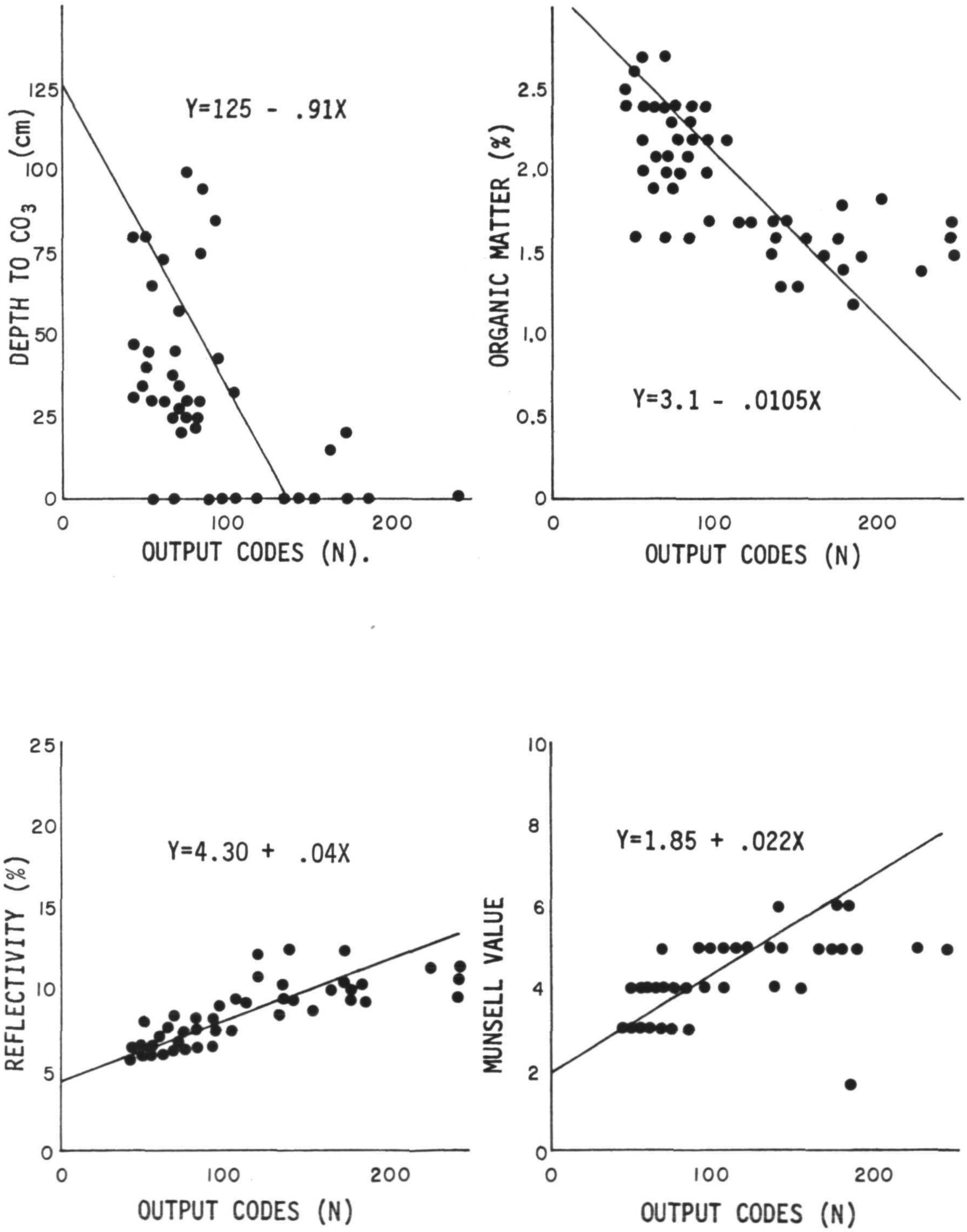


Figure 12. Regression analysis of neutral digital output codes(N) and soil property variables for Field #1.

TABLE 6. CORRELATION COEFFICIENTS FOR FIELD #2.

	Depth to CO_3	Depth to B	Thickness of B	Refl.+	Organic Matter	Bulk Density	Neutral	Red	Green	Blue
Depth to CO_3	1.000**									
Depth to B	.460**	1.000**								
Thickness of B	.391**	-.360**	1.000**							
Refl.+	-.260*	-.454**	.209	1.000**						
Organic Matter	.137	.543**	-.378**	-.522**	1.000**					
Bulk Density	-.113	-.576**	.450**	.414**	-.623**	1.000**				
Neutral	-.321	-.649**	.323**	.636**	-.704**	.711**	1.000**			
Red	-.248*	-.486**	.199	.542**	-.600**	.603**	.815**	1.000**		
Green	-.333**	-.700**	.379**	.603**	-.703**	.745**	.985**	.806**	1.000**	
Blue	-.316**	-.626**	.313**	.616**	-.695**	.674**	.907**	.869**	.919**	1.000**

* significant at the .05 level with 66 d.f. (>.239)
** significant at the .01 level with 66 d.f. (>.311)
\+ reflectivity at .58 μm

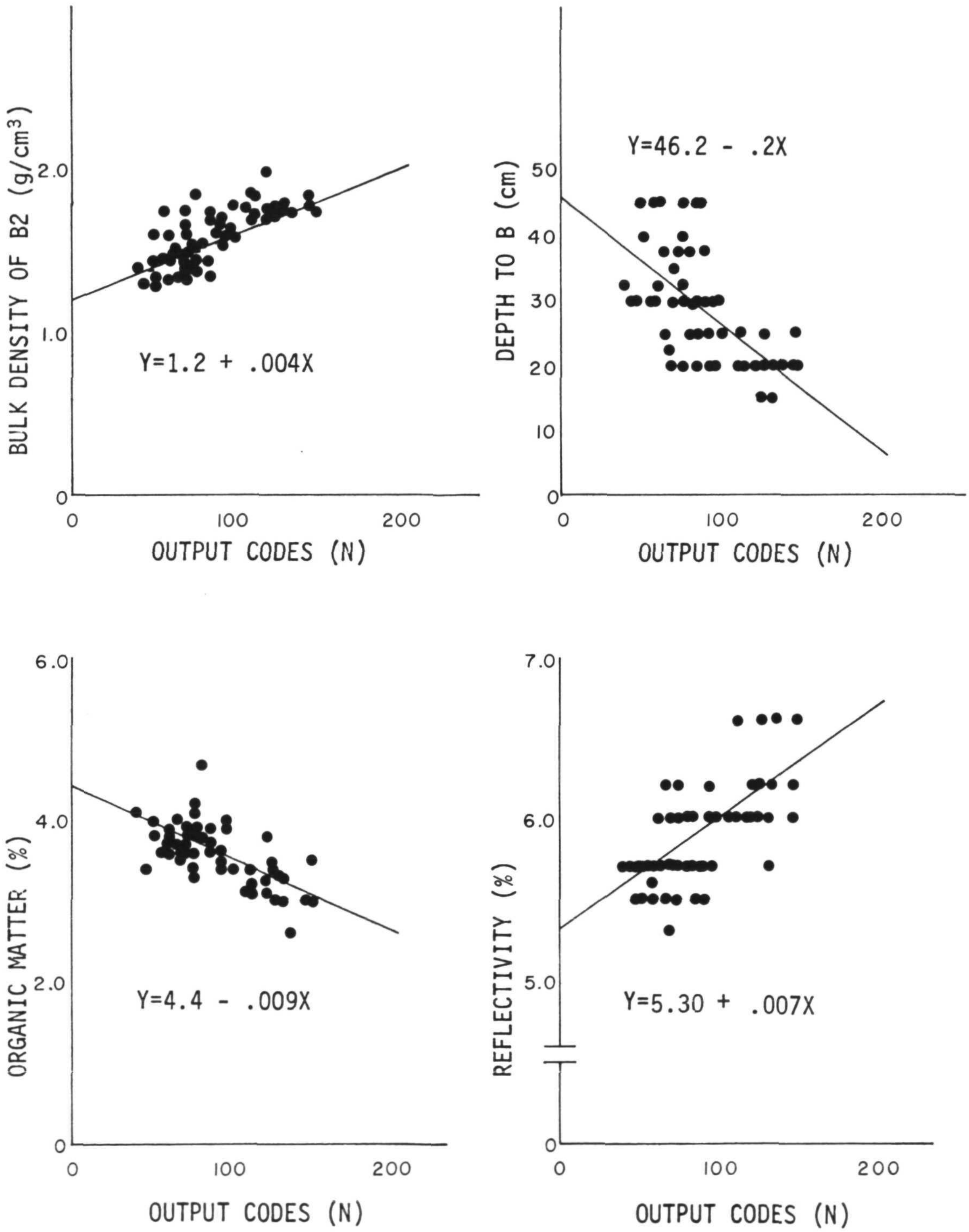


Figure 13. Regression analysis of neutral(N) digital output codes and soil property variables for Field #2.

lighter-colored A2 horizon found above the B2t horizon of claypan soils. The significant reduction in organic matter content associated with increased output codes and reflectance is also due to the leached A2 horizon. Therefore, the increase in output codes (lighter tones) with increasing bulk density and surface reflectance observed in Figure 13 is primarily due to the decreased depth to the A2 horizon. The observed decrease in output codes (darker tones) with increasing organic matter content and increasing depth to the B horizon indicate the A2 and the claypan are either below the plow layer or not present. Although significantly correlated, depth to carbonates and thickness of B horizon were not as highly correlated with film data as organic matter content, bulk density, and depth to the B horizon; because these properties are not manifested at the surface.

Pattern Recognition

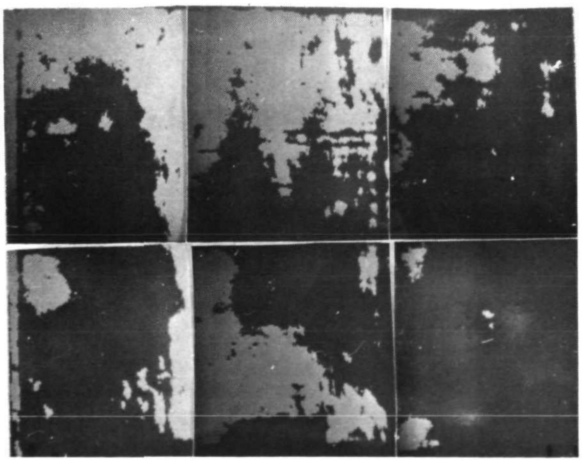
The results obtained by training the classifier on the sample areas using 16 different combinations of the four features (filtered data) are presented as Table 7. The figures indicate the accuracy of the classifier is high for any feature or combination of features except the red-filtered data. The reason for the lower correct classification with the red filter in Field #2 was not apparent. The subsequent classification of Fields #1 and #2 was accomplished using all four features (NRGB). The results of the classification were displayed on the color television monitor of SADE, photographed, and assembled in a mosaic. Mosaics of Field #1 and #2 are shown in Figure 14.

TABLE 7. PATTERN RECOGNITION RESULTS FOR TRAINING SAMPLES

Field #1		Field #2	
Features (Filters)	Percent Correct Classification	Features (Filters)	Percent Correct Classification
NRGB	98.02	NGB	97.78
NGB	97.98	NRGB	97.59
NRG	96.84	NB	96.55
NB	96.75	NG	96.40
NR	96.69	GB	96.30
NRB	96.65	RGB	96.30
RGB	96.49	NRG	96.21
GB	96.31	NRB	96.11
NG	96.28	G	94.24
N	96.00	RG	94.24
RG	95.86	NR	93.15
G	95.29	N	93.10
B	92.94	RB	88.62
RB	92.61	B	87.59
R	90.51	R	66.89

N = neutral filter, R = red filter, G = green filter, B = blue filter

FIELD #1



FIELD #2

Figure 14. Computer classification from SADE display. Scale=1:10,500.

The computer classification of Field #1 demonstrated that the classifier could be trained on a sample area containing an eroded soil and a sample area typical of an uneroded soil and could subsequently classify the whole field. The resulting classification was compared with the field data using the F-test from the analysis of variance to determine if there was a significant difference between the two classes in terms of the soil properties. The F-tests verified what had been observed from the correlation/regression analysis. The means for surface reflectance, Munsell value, organic matter content, and depth to CO_3 were all significantly different between the two classes. The means and standard deviations of each class for each soil property and the F-values are shown in Table 8.

The computer classification of Field #2 showed how the classifier, when provided with appropriate sample areas for training, could classify the rest of the field based on the samples. The F-values from the analysis of variance of the two classes reinforced the results from the correlation analysis. The F-tests showed the greatest difference between classes was in terms of bulk density of the B2 horizon, organic matter content, and depth to the B horizon, which are indicative of the claypan limitation. Surface reflectance and thickness of the B horizon were significantly different to a lesser degree and depth of CO_3 was not significantly different between the two classes. Table 9 contains the means and standard deviations of each class for each soil property and the F-values.

TABLE 8. RELATIVE SIGNIFICANCE OF CLASSIFICATION TO GROUND TRUTH VARIABLES FOR FIELD #1

Soil Properties	Class 1 & 2		Class 1		Class 2		F
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
Reflectivity	.081	.018	.069	.010	.098	.012	92.3**
Value	4.24	.84	3.67	.54	5.0	.52	82.5**
Organic Matter	1.96	.42	2.21	.33	1.61	.26	54.6**
Depth to CO_3	10.2	11.7	17.3	10.7	.6	2.0	54.3**
Slope	1.8	.9	1.4	.6	2.5	.8	30.5**
Depth of A	11.9	6.4	14.2	6.5	8.8	5.1	11.0**
Depth to C	14.0	8.9	18.8	8.9	7.5	2.7	7.7**
Position	2.4	.9	2.6	1.0	2.0	.5	5.1*
Elevation	1288.2	4.9	1287.3	5.7	1289.3	3.5	2.2ns
Aspect	4.4	2.7	4.4	2.7	4.4	2.7	.005ns

** significant at the .01 level with 1 and 52 d.f.(>7.22)
* significant at the .05 level with 1 and 52 d.f.(>4.05)
ns nonsignificant at the .05 level

TABLE 9. RELATIVE SIGNIFICANCE OF CLASSIFICATION TO GROUND TRUTH VARIABLES FOR FIELD #2

Soil	Class 1 & 2		Class 1		Class 2		F
Properties	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	1 vs 2
Bulk Density	1.61	.17	1.51	.13	1.75	.08	80.1**
Organic Matter	3.59	.36	3.78	.24	3.33	.32	44.1**
Depth to B	11.4	3.4	13.2	3.1	8.9	1.8	43.7**
Reflectivity	.059	.003	.057	.002	.061	.003	25.5**
Thickness of B	15.9	5.3	14.2	5.1	18.2	4.7	10.7**
Depth to CO_3	24.3	5.0	25.2	4.9	23.1	4.8	2.9ns

**significant at the .01 level with 1 and 65 d.f. (>7.07)
ns nonsignificant (<4.0) at the .05 level

Density Slicing

The Spatial Data analysis revealed that the results obtained from pattern recognition using four features (neutral, red, green, and blue) were closely approximated by density slicing of the unfiltered film. This probably would not hold true if the fields had been covered by a crop canopy, but under fallow conditions the infrared reflectance was minimal. A comparison of the two representations shown in Figure 15 reveals a close agreement, although the computer representation is exaggerated in the horizontal.

A comparison of the results obtained from the approach based on photo interpretation and the approach based on sample areas indicated that differing results can be obtained using this technique depending on the criteria and procedures used. The flexibility and area measuring capability make the devise a powerful tool if used properly. However, the ability of the operator to control the output requires certain rules and procedures be followed to insure reproducible results unaffected by bias or chance. A comparison of all three approaches to the density slicing method of analysis for Field #2 is presented as Figure 16. The results from K-Class were considered correct for the purpose of comparison. Similar results were obtained for Field #1.

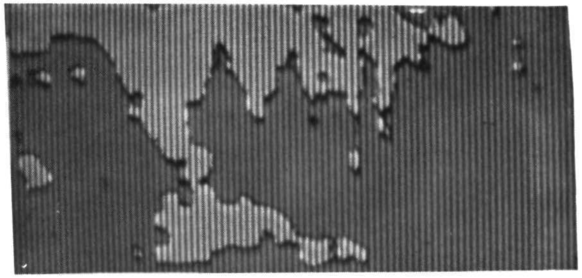
In attempting to evaluate the methods of analysis it became apparent that all four methods had a place in the analysis of the imagery. Initially the photograph required visual inspection to determine if the quality of the image warranted further analysis. The next step was the detailed study of sample areas with digital analysis

FIELD #1

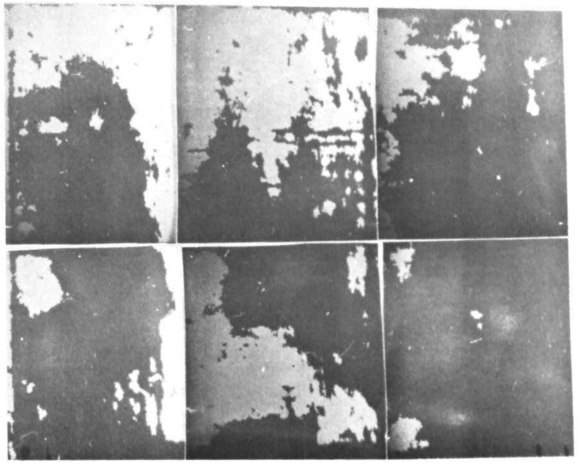
K-CLASS

DENSITY SLICING

FIELD #2

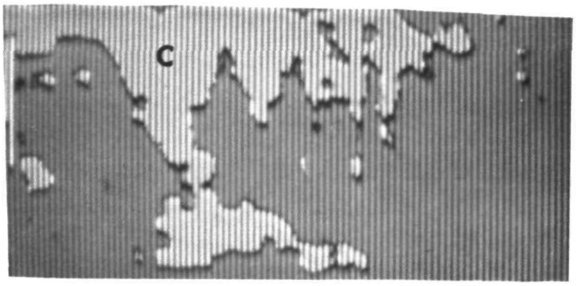


DENSITY SLICING

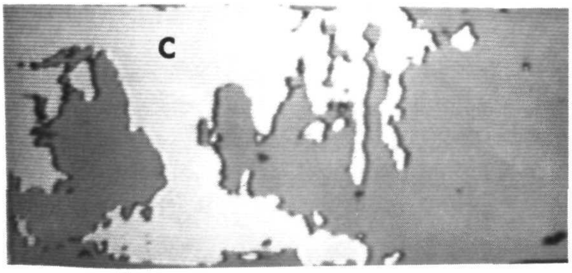


K-CLASS

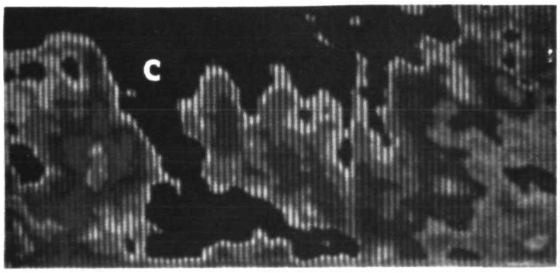
Figure 15. A comparison of computer classification with density slicing. Scale=1:10,500 .



MATCHED TO K-CLASS
CLAYPAN(C)=29%



BASED ON PHOTO INTERPRETATION
CLAYPAN(C)=37%



BASED ON DENSITY RANGE
AND FIELD DATA
CLAYPAN(C)=30%

Figure 16. Spatial Data displays of Field #2 using three approaches to density slicing. Scale=1:10,500.

to determine the relationship of the properties being studied to the film data. Computer classification and pattern recognition then grouped the data using decision theory and provided a basis for extrapolation using the less accurate, but more efficient density slicing technique. Examples of the steps in the analysis of Field #2 are presented in Figure 17.

VISUAL

SADE

K-CLASS

DENSITY
SLICING

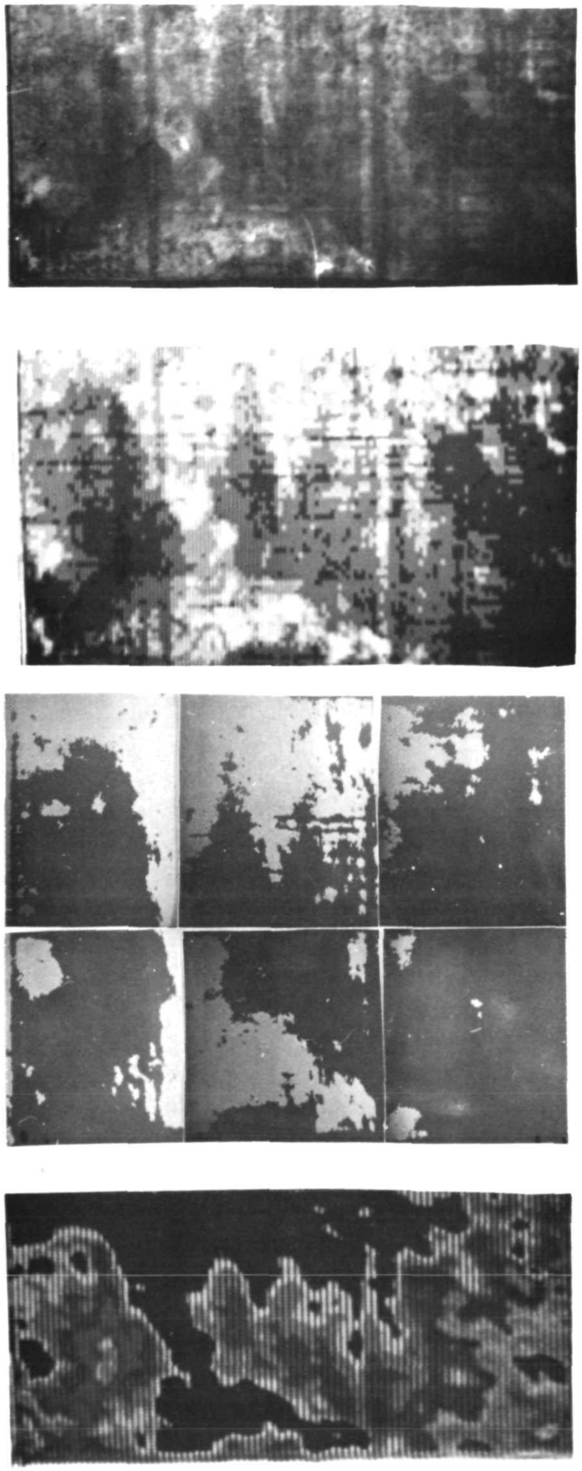


Figure 17. Comparison of outputs from analysis methods for Field #2.

SUMMARY AND CONCLUSIONS

During the 1972 growing season field data were gathered to explain the tonal variations observed during previous work. A 14 hectare field containing eroded soils and a 32 hectare field containing claypan soils were studied in detail. Soil profile samples were obtained from each field with a probe truck and were observed, measured, and analyzed for several soil properties characteristic of erosion and claypan limitations. The field data were compared with film data from 70 mm color infrared photography obtained on May 14, 1971 from 2440 meters.

Four methods of analysis were employed in the study. The visual analysis primarily involved the photo interpretation approach required to quickly evaluate photographs and photographic patterns. The digital analysis required the use of the Signal Analysis and Dissemination Equipment for initial digitization and storage of the film data, and for subsequent display on the color television monitor. The film data were then statistically compared to the field data. The computer classification analysis utilized pattern recognition techniques to train on sample data and subsequently classified both fields based on film transmittance data from the previous digital analysis. The field data from each class was then tested for a significant difference between classes. A density slicing analysis was conducted using three different approaches.

The results from the analyses showed that in the fields studied photographic tone was in fact recording the reflectivity of the soil

surface which was a good indicator of several soil properties characteristic of erosion limitations and claypan limitations. The higher reflectance, hence lighter tones, in claypan areas was due to the light-colored A2 horizon overlying the claypan and becoming mixed into the plow layer. The light tones and higher reflectance of eroded soils were due to the exposure and incorporation of the light-colored subsoil containing $CaCO_3$.

The results of the study supported the conclusion reached by other researchers that the red band of the spectrum is the best for measuring reflectance from soils. The unfiltered data yielded the best results for the field containing the erosion limitation and the green-filtered data (red band) was best for the claypan field. The data from the green band and the infrared band yielded lower correlations in nearly all cases.

A procedure for the analysis of remote sensing imagery was developed for use with the SADE and Spatial Data equipment consisting of an initial visual analysis, a subsequent detailed analysis of sample areas where field sampling was intensified to determine soil property/film density relationships, a computer classification based on the detailed analysis, and a final density slicing analysis for extrapolating from the computer classification.

With reference to the specific objectives set forth at the beginning of this report, the detailed information gathered during this study has established that photographic tone has a direct relationship with surface reflectivity which is directly related to

the claypan limitation and the erosion limitation. The red band of the visible spectrum has been established as the best band for the detection of erosion and claypan limitations. A technique has been established for the utilization of state-of-the-art data analysis equipment for detecting and mapping soil limitations from remote sensing imagery.

Recommendations for Further Study

Although the techniques developed were successful in individual fields using the soils data available, they may not work when analyzing a large area or field containing both claypan and erosion limitations because the same features are used for discrimination. Another remotely measured variable such as slope or temperature would be necessary to separate the two limitations when they occur together because their photographic tone could be very similar.

A study with the objective of applying the techniques developed on a field basis to a section or many sections is needed to thoroughly test the feasibility of the remote sensing approach to mapping soil limitations. The addition of a sensor that would detect small changes in elevation and convert them to slope as it scans across a flightline, such as a laser altimeter, would provide the slope information that is so necessary to soil survey and terrain analysis. Until a sensor package and/or analysis technique is developed that will provide surface temperature and elevation simultaneously with photographic tone, the remote sensing of soils and soil limitations over large areas will be handicapped.

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APPENDICES

APPENDIX A

Equipment and Instrument Description

Field Equipment

Probe truck w/ rear-mounted probe

Acid bottle w/ .1N HCl

Munsell color book

Soil sampling cans, boxes, and forms

Engineers steel tape and pins

Aerial Equipment

Aircraft - Twin Engine Beechcraft Model RC45J

70 mm Hasselblad cameras
- B/W film (2404) w/ green (#58) filter (.47-.61 μm)
- B/W film (2404) w/ red (25A) filter (.59-.70 μm)
- B/W film (2403) w/ near-infrared filter (.68-.90 μm)
- Color IR film (2443) w/ G15/30M filter (.51-.90 μm)

Barnes precision radiation thermometer, PRT-5 (8.0-14.0 μm)

Daedalus thermal infrared scanner (filtered 4.5-5.5 μm)

Mark I-G Incoming solameter (.35-1.15 μm)

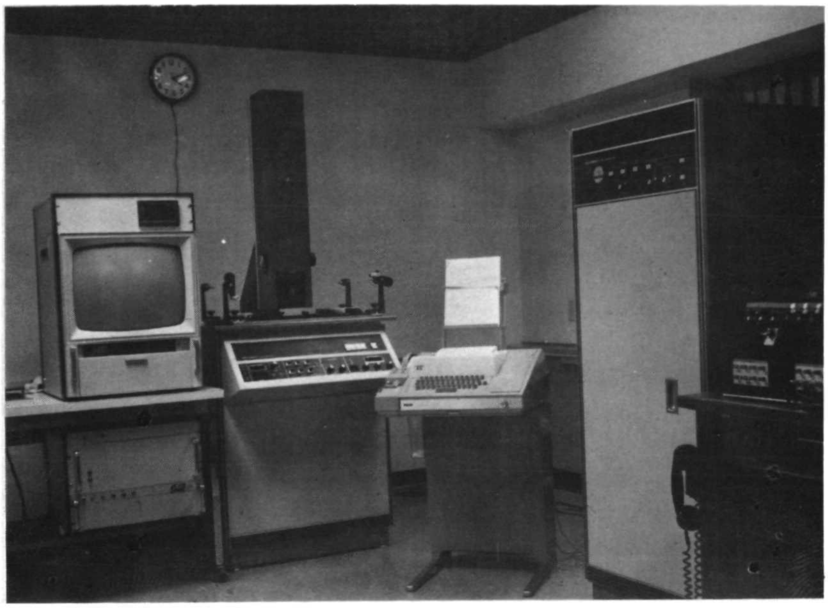
Mark I-RF Outgoing solameters (3)
- #58 green - (.47-.61 μm)
- #25A red - (.59-.70 μm)
- #89B near-infrared - (.68-.90 μm)

Laboratory Equipment

Signal Analysis and Dissemination Equipment (Figure A.1)

Spatial Data Datacolor Model 703 (Figure A.2)

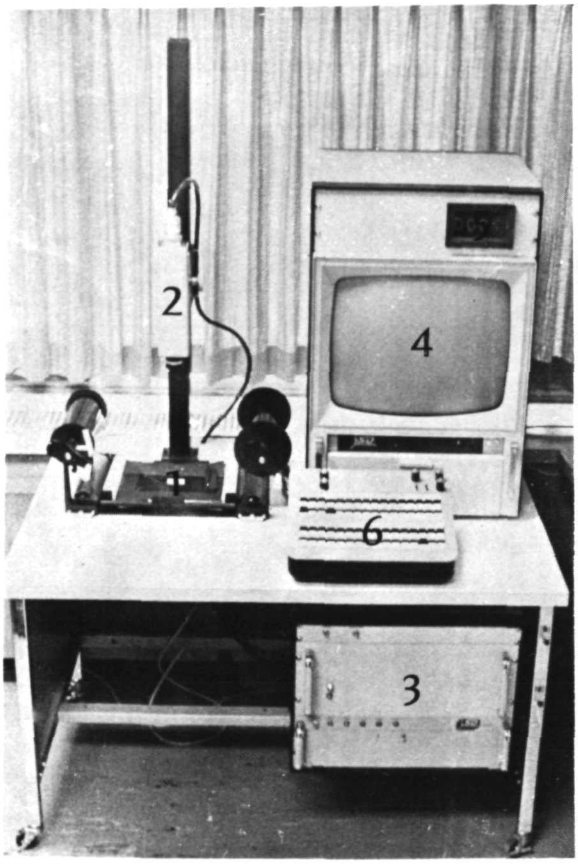
ISCO Model SR Spectroradiometer Recorder (Figure A.3)



SADE was designed as a state of the art data analysis system with a highly flexible modular design. In the independent off-line mode the system provides monitor display of digital film or analog tape data and transmission of analog information to the film printer. When on line with the computer the system provides transmission of digitized image data and analog tape data to the computer and transmission of data stored or transformed in the computer back to the display monitor or the film printer. The system is composed of the following components:

1. Image digitizer (image dissector tube)
2. Data control and conversion unit
3. Lockheed 417 seven track analog tape recorder
4. Daedalus film printer
5. Band pass filters
   - Red - .59-.70 μm
   - Green - .47-.62 μm
   - Blue - .36 - .50 μm

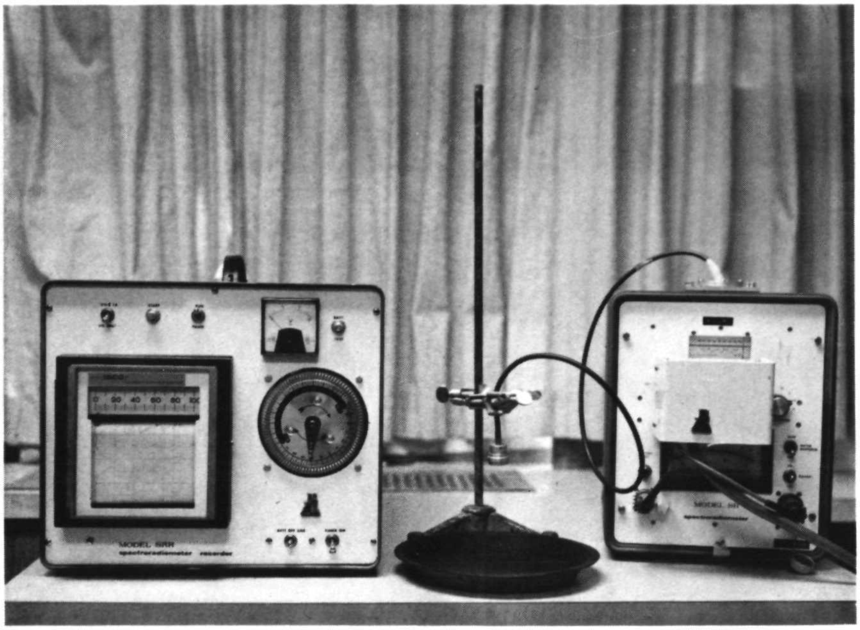
Figure A.1 Signal Analysis and Dissemination Equipment.



The Spatial Data system is an instrument for analyzing density patterns. The transparency is viewed by a black and white television camera, and the electronic signal from the camera is separated with respect to the various density levels of the transparency. The density levels are encoded into colors selected by the operator and displayed on the color television monitor. Up to 32 density levels or colors may be used at one time. The system has the following components:

1. Light box to illuminate the film
2. Precision monochromatic TV camera
3. Electronic color analyzer
4. Color television monitor
5. Electronic planimeter
6. Control keyboard

Figure A.2 Spatial Data Datacolor Model 703.



The ISCO Model SRR Spectroradiometer Recorder-Scanner measures the intensity of light. The scanner component contains two detectors recessed in the cabinet that are sensitive to spectral energy. One detector is sensitive to visible light (.38-.75 μm) and the other is sensitive to infrared energy (.75-1.05 μm). The scanner can measure intensity at any desired wavelength within its sensitivity range or can scan the visible or infrared range. Intensity is measured as percent of full-scle for one of eight scale ranges and subsequently compared to a calibration curve. The remote probe sensing head permits the measurement of spectral energies for small areas. The strip chart recorder provides an inked plot of percent of full scale versus wavelength for each scan of the visible or infrared range. Both scanner and recorder can be operated by battery or line power.

Figure A.3 Spectroradiometer Recorder-Scanner.

APPENDIX B

MISSION PARAMETERS AND DATA

Mission Parameters

Information pertaining to general flight parameters, sensor settings and ranges, and atmospheric conditions for the aerial mission conducted on May 14, 1971 are presented in Table B.1. The study utilized photography from Lines 3 and 4.

Incoming Radiation and Exposure Settings

Average values for incoming radiation (cal/cm^2/min) from the incoming solameters for each overpass are presented in Table B.2. The table also contains the exposure settings for the 70mm Hasselblad cameras.

Field Data Sampling Form

An example of the form used to record the detailed soil profile data is included. The form was completed in the field for each grid point in Fields #1 and #2.

Data

Soil property data from field and laboratory measurements and film data (output codes from SADE) for Fields #1 and #2 are included at the back of Appendix B. Soil property characteristics that were not quantitative in nature were assigned a number within a range consistent with the variability of the characteristic. Depth measurements were in inches, weights were measured in grams, and reflectivity was measured relative to incoming radiation.

TABLE B.1 MISSION PARAMETERS AND ATMOSPHERIC CONDITIONS

Date	Time	Line	Alt. (1000ft)	Cameras		PRT			Incoming Solameter			Thermal Scanner					
				Film	Filter	FOV	Min.	Max.	Max.	Min.	Ave.	Gain	Wavelength	FOV	Head.	Clds.	Haze
14	11:36	4	8.0	2402	58	2^o	-	-	65	62	63	65	4.5-5.5	60^o	270^o	Clr	Mod
May	11:43			2402	25A												
				2443	G15/30M												
				2424	89B												
	11:52	3	8.0	"	"	"	"	"	64	61	63	60	"	"	90^o	"	"
	11:58																
	12:24	5	8.0	"	"	"	"	"	71	68	69	68	"	"	270^o	"	"
	12:33																

TABLE B.2 INCOMING RADIATION AND EXPOSURE SETTINGS

Date	Line	Incoming Radiation*		Shutter Speed (sec)	F-Stop			
		MV	Cal.		B/W-58	B/W-25A	G15/30M	B/W-89B
May 14	4	6.3	1.214	1/250	5.6	11	8-11	11-16
May 14	3	6.3	1.214	1/250	5.6	11	8-11	11-16
	5	6.9	1.316	1/250	5.6	11	8-11	11-16

*Incoming Radiation ($cal/cm^2/min$) = millivolts (MV) x .17 +.143

REMOTE SENSING INSTITUTE
SOUTH DAKOTA STATE UNIVERSITY

SOIL PROFILE DATA

Location: ________________ Field: ______________ Sample: ________

Prepared by: ____

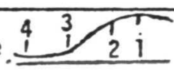
Date: __________________________________

Horizon	Depth	Color		Texture	Structure	Consistence			Reaction	Other Features
		Dry	Moist			Dry	Moist	Wet		

Elevation: ______________________ Drainage: ______________________

Relief: ________________________ Depth of Carbonates: ______________

Depth to Lithologic Discontinuity: ______________________________

Degree of Slope: __________ Position on Slope 

Aspect: ________

Notes: ____

____

Figure B.1 Field data sampling form.

TABLE B.3 DATA FOR FIELD #1

Grid Point	Depth to CO_3 (in)	Depth of A (in)	Depth to C (in)	Elevation	Hue	Value	Chroma	Reflectivity (%)	Organic Matter (%)	Slope (%)	Position	Aspect	Soil Series	Neutral	Red	Green	Blue
1	32	18	36	1289.5	2.5	3	2	5.7	2.5	1	4	1	60	44	20	38	27
2	0	9	9	1294.3	2.5	5	2	8.0	2.4	2	1	1	65	93	22	73	36
3	11	6	11	1287.7	2.5	4	2	6.4	2.3	2	2	1	60	82	22	69	35
4	14	8	18	1280.0	2.5	3	2	6.0	2.6	1	3	1	10	50	20	40	29
5	0	16	18	1277.0	10.0	4	1	6.6	2.7	0	4	9	10	56	21	54	31
6	30	26	30	1278.3	2.5	3	2	6.4	2.4	0	4	9	10	85	23	63	34
7	0	8	8	1286.1	2.5	5	2	8.2	1.6	2	3		70	69	23	52	31
8	0	6	6	1293.5	2.5	5	2	9.3	2.2	2	2		70	107	25	72	38
9	13	12	13	1295.0	2.5	4	2	7.5	2.2	1	1	3	65	106	25	71	38
10	10	24	24	1294.0	2.5	4	2	7.3	2.2	1	1	9	70	77	23	57	33
11	40	12	40	1292.5	10.0	4	2	6.2	2.4	1	3	7	60	75	22	56	32
12	0	6	6	1293.0	5.0	5	3	10.6	1.7	1	1	7	70	244	36	160	69
13	26	12	26	1286.1	2.5	3	2	6.0	2.2	3	3		60	56	21	45	31
14	32	32	32	1279.0	2.5	4	2	6.6	3.0	0	4	9	10	50	20	41	30
15	29	10	30	1282.3	2.5	4	2	7.1	2.4	1	3		10	61	21	55	31
16	0	30	00	1293.0	5.0	6	3	12.2	1.3	2	2	1	70	175	30	119	62
17	12	8	12	1294.6	2.5	4	2	6.8	2.4	1	1	9	60	58	21	49	31
18	16	8	16	1291.9	2.5	4	2	8.0	1.6	1	1		60	51	20	42	28
19				1278.3										72	22	53	22
20	10	16	18	1281.5	2.5	3	2	6.4	2.1	2	3	5	10	69	21	55	33
21	12	12	12	1284.5	2.5	3	2	6.0	1.9	1	2	5	60	62	22	50	31
22	34	17	34	1279.5	2.5	4	2	6.6	2.2	0	4	9	10	94	21	63	37
23	0	11	11	1281.6	2.5	5	2	8.8	1.7	3	2	6	60	96	22	63	35
24	0	7	7	1285.0	2.5	4	2	8.6	1.6	3	2	5	70	154	25	104	48
25	8	8	8	1287.2	2.5	5	2	10.4	1.6	3	2	5	70	173	27	112	51
26	23	23	23	1289.2	2.5	3	2	6.4	1.9	2	2	5	60	72	22	57	33
27	0	7	7	1281.9	2.5	5	2	9.1	1.5	2	3	5	70	188	30	154	51
28	18	18	18	1283.2	2.5	3	2	6.2	2.7	2	3	7	70	70	22	48	30
29	0	6	6	1287.0	2.5	5	2	9.5	1.4	2	2	7	70	178	31	112	47
30	0	14	14	1289.1	2.5	4	2	9.3	1.7	3	2	5	60	137	26	95	44

TABLE B.3 DATA FOR FIELD #1 (con't)

Grid Point	Depth to CO_3 (in)	Depth of A (in)	Depth to C (in)	Elevation	Hue	Value	Chroma	Reflectivity (%)	Organic Matter (%)	Slope (%)	Position	Aspect	Soil Series	Neutral	Red	Green	Blue
31	17	24	24	1291.2	2.5	4	2	7.5	2.0	2	2	5	60	95	21	70	37
32	12	12	12	1284.4	2.5	4	2	7.5	1.6	2	3	5	70	83	21	60	35
33	17	17	17	1284.2	2.5	4	2	6.8	2.1	1	4	7	60	71	23	51	33
34	6	6	6	1288.1	2.5	5	2	10.0	1.5	2	2	7	70	164	29	108	50
35	0	6	6	1291.0	2.5	5	2	9.5	1.6	2	2	7	70	243	34	144	63
36	0	8	8	1292.6	5.0	5	3	10.0	1.8	2	2	5	70	177	26	136	59
37	38	9	13	1286.0	2.5	3	2	6.4	2.2	2	3	5	50	87	22	62	36
38	0	7	7	1289.0	2.5	4	2	9.1	1.6	2	2	7	70	137	26	95	45
39	0	10	10	1291.6	2.5	5	2	11.1	1.4	2	2	7	60	227	38	124	44
40	19	19	19	1291.4	2.5	3	2	6.6	2.4	2	3	8	60	46	19	39	27
41	11	10	10	1294.2	10.0	3	3	6.6	2.3	1	1	8	65	72	22	57	33
42	8	8	8	1292.0	2.5	4	2	7.5	2.1	1	1	2	70	64	21	50	31
43	12	12	12	1292.2	2.5	4	2	7.7	2.0	2	2	8	60	68	22	57	32
44	9	9	9	1293.8	5.0	4	3	8.2	2.1	2	2	1	70	82	22	64	34
45	0	9	9	1293.6	2.5	4	2	8.2	2.0	1	2	2	70	70	22	61	33
46	18	18	18	1290.0	2.5	4	2	6.4	2.0	2	3	8	60	54	20	42	29
47	0	8	8	1291.6	2.5	5	2	9.1	1.7	2	2	1	70	113	24	78	38
48	0	12	12	1292.4	2.5	6	2	12.4	1.3	2	2	1	70	140	25	94	46
49	0	7	7	1291.0	5.0	5	2	10.8	1.7	2	2	1	70	121	24	90	39
50	0	6	6	1290.1	5.0	5	2	9.3	1.7	3	2	8	70	142	26	93	42
51	0	8	8	1291.0	2.5	5	2	8.4	1.5	4	2	1	70	134	26	89	42
52	0	6	6	1290.0	5.0	5	3	11.5	1.5	4	2	1	70	247	34	151	65
53	0	6	6	1287.0	2.5	5	2	10.2	1.6	3	3	1	70	136	26	90	44
54	0	8	8	1288.3	2.5	6	2	10.2	1.2	4	2	1	70	183	30	120	53
55	15	15	15	1286.0	10.0	4	2	6.2	2.4	2	4	2	60	69	21	52	32

TABLE B.4 DATA FOR FIELD #2

Grid Point	Depth to CO_3 (in)	Depth to B (in)	Thickness of B (in)	Elevation (ft)	Hue	Value	Chroma	Reflectivity (%)	Organic Matter (%)	Bulk Density of B	Soil Series	Neutral	Red	Green	Blue
1	27	18	9	1297.0	5.0	4	2	5.7	3.9	1.61	50	48	25	36	26
2	24	8	28					6.2	3.5	1.55	25	92	27	69	34
3	23	8	24					6.2	3.3	1.79	25	131	29	92	37
4	24	10	22					6.0	3.5	1.72	25	124	27	87	36
5	20	8	19					6.0	3.8	1.98	25	118	28	89	36
6	25	12	24					5.7	3.7	1.65	30	69	25	55	29
7	21	8	17					6.0	3.8	1.65	25	74	26	61	31
8	24	9	15					5.5	3.5	1.51	40	66	24	55	27
9	22	12	10					5.7	3.7	1.29	45	45	25	36	27
10	18	13	5					5.7	4.2	1.44	55	76	26	55	31
11	22	13	9					5.7	4.1	1.40	55	40	25	33	25
12	22	12	10					6.0	3.4	1.63	35	98	28	72	33
13	31	16	20					5.7	3.6	1.47	30	75	26	57	31
14	30	16	14					6.0	3.7	1.42	30	75	26	54	30
15	24	12	12					5.5	3.8	1.68	30	90	26	67	33
16	24	8	25					6.0	4.0	1.59	30	94	28	71	34
17	22	8	14					5.3	3.6	1.43	50	68	27	56	31
18	30	16	14					5.5	3.8	1.31	30	51	24	40	29
19	32	15	17					5.7	4.7	1.55	50	80	26	57	30
20	28	16	16					5.7	3.8	1.33	40	51	26	40	28
21	17	8	17					6.0	3.4	1.71	25	110	27	80	35
22	28	13	21					5.5	3.7		30	59	22	44	25
23	30	13	21					5.5	3.8	1.42	40	72	26	55	30
24	20	8	17					5.7	3.6	1.70	20	85	26	65	30
25	19	10	20					5.7	3.4	1.67	30	91	27	74	33
26	36	18	18					5.7	3.7	1.61	40	61	26	47	28
27	24	12	12					5.5	4.0	1.46	50	49	23	40	28
28	22	10	12					6.0	3.9	1.44	45	83	25	55	28
29	18	10	8					6.2	4.0	1.35	50	64	25	46	27
30	28	12	16					6.0	3.9	1.44	40	60	26	44	28
31	18	18	6					6.0	4.1	1.50	50	76	27	53	31
32	22	12	10					6.2	3.9	1.46	50	74	26	53	29
33	22	12	10					5.7	3.9	1.44	45	70	27	51	28
34	24	10	10					6.0	3.8	1.54	50	81	24	59	31
35	18	15	9					5.7	3.8	1.50	50	72	28	52	30

TABLE B.4 DATA FOR FIELD #2 (con't)

Grid Point	Depth to CO_3 (in)	Depth to B (in)	Thickness of B (in)	Elevation (ft)	Hue	Value	Chroma	Reflectivity (%)	Organic Matter (%)	Bulk Density	Soil Series	Neutral	Red	Green	Blue
36	28	15	13	1297.0	5.0	4	2	5.7	3.9	1.50	50	62	24	47	27
37	23	18	13					5.7	3.6	1.46	50	58	25	45	29
38	22	12	10					5.7	3.9	1.33	50	71	25	48	27
39	35	18	17					5.7	3.7	1.54	45	84	26	56	27
40	31	15	16					5.7	3.7	1.52	45	63	23	45	23
41	22	18	6					5.5	3.6	1.36	45	86	26	56	30
42	30	15	15					5.7	3.6	1.62	45	89	27	62	36
43	20	12	14					6.0	3.8	1.54	45	76	24	58	30
44	32	12	20					5.1	3.6	1.74	30	57	26	42	30
45	30	8	22					6.6	3.1	1.71	30	111	28	73	34
46	24	8	16					6.6	2.6	1.75	30	135	30	94	42
47	30	8	22					6.0	3.0	1.78	30	130	30	89	37
48	30	14	16					6.0	3.6	1.61	40	70	26	54	30
49	36	12	23					6.2	3.3	1.86	30	75	27	56	32
50	24	8	27					6.2	3.0	1.79	20	144	30	95	40
51	18	8	10					6.0	3.0	1.85	20	144	31	99	41
52	26	6	20					5.7	3.3	1.80	30	129	29	92	37
53	25	12	13					5.7	3.6	1.74	40	69	26	52	29
54	34	12	22					5.7	3.9	1.59	30	95	26	73	31
55	20	8	18					6.0	3.1	1.77	20	120	28	84	35
56	24	8	22					6.0	3.2	1.84	25	110	27	82	33
57	20	8	16					5.7	3.4	1.86	25	73	26	57	29
58	24	12	20					5.7	3.7	1.75	30	85	25	59	30
59	18	8	20					6.2	3.1	1.70	25	120	25	82	31
60	18	8	10					6.0	3.5	1.75	25	147	31	96	36
61	24	8	16					6.0	3.1	1.77	25	108	28	77	35
62	23	10	20					6.0	3.4	1.83	30	111	27	77	33
63	24	10	14					6.0	3.4	1.79	30	99	26	69	31
64	18	6	16					6.2	3.4	1.70	20	124	29	88	38
65	17	8	9					6.2	3.3	1.68	30	120	27	82	37
66	24	8	23					6.6	3.0	1.78	25	127	29	86	38
67	18	10	18					6.6	3.0	1.76	30	147	31	98	41